Industrial QUALITY CONTROL

JANUARY, 1954 Vol. X No. 4

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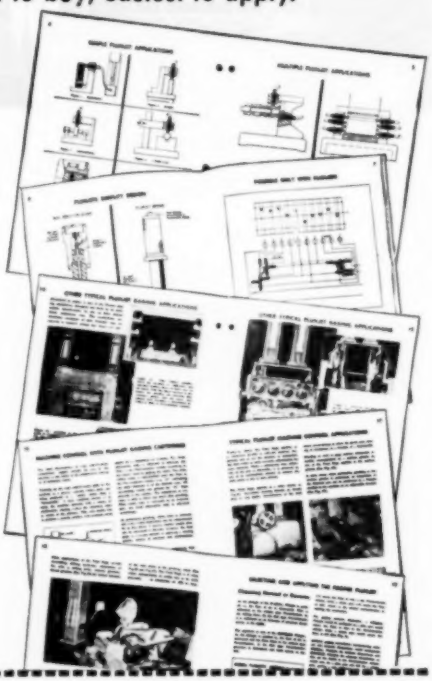

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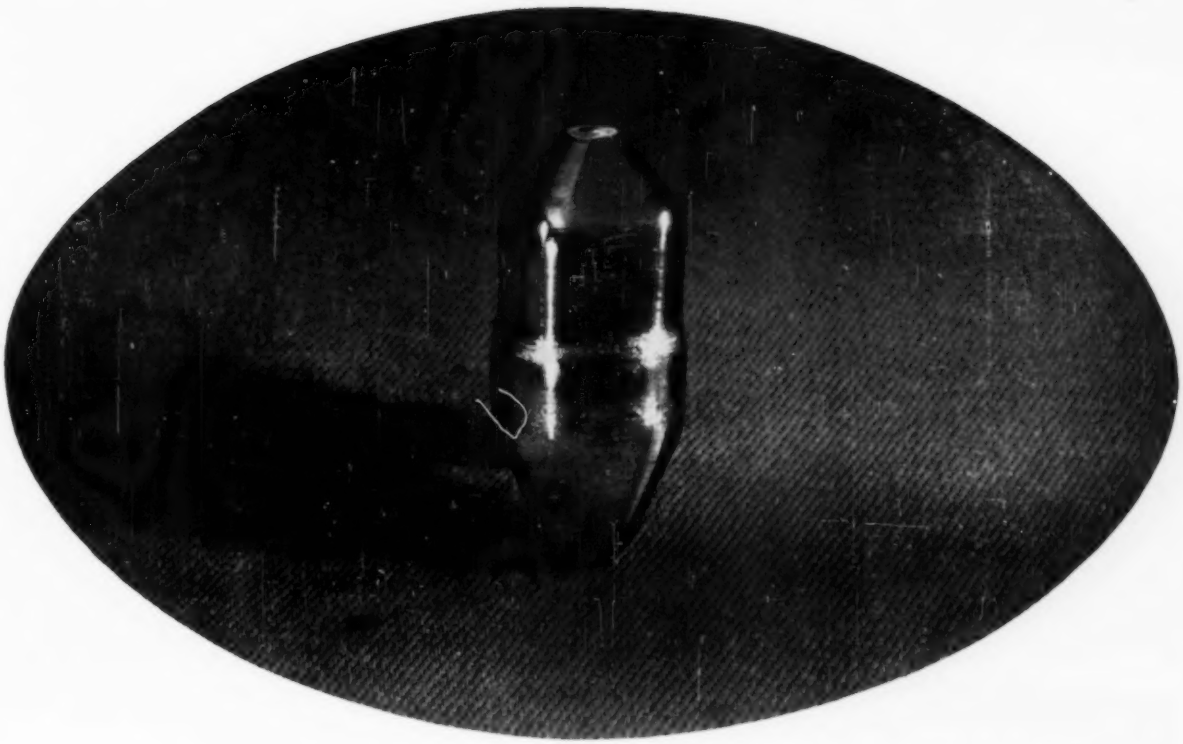


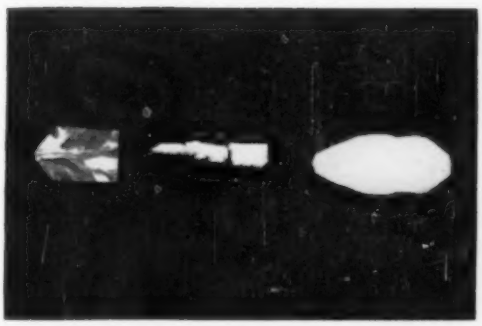
Germanium crystal grown at Bell Telephone Laboratories (life size). It is sliced into hundreds of minute pieces to make *Transistors*. Transistor action depends on the flow of positive current-carriers as well as electrons, which are negative. Arsenic —a few parts per 100,000,000—added to germanium produces prescribed excess of electrons. With gallium added, positive carriers predominate. Latest junction type *Transistor* uses both kinds of germanium in the form of a sandwich.

THEY GREW IT FOR TRANSISTORS

Heart of a ***Transistor*** – Bell Telephone Laboratories' new pea-size amplifier – is a tiny piece of germanium. If ***Transistors*** are to do their many jobs well, this germanium must be of virtually perfect crystalline structure and uniform chemical composition. But it doesn't come that way in nature.

So–Bell scientists devised a new way to *grow* the kind of crystals they need, from a melt made of the natural product. By adding tiny amounts of special alloying substances to the melt, they produce germanium that is precisely tailored for specific uses in the telephone system.

This original technique is another example of the way Bell Laboratories makes basic discoveries – in this case the ***Transistor*** itself – and then follows up with practical ways to make them work for better telephone service.



Section of natural germanium, left, shows varying crystal structure. At right is sectioned single crystal grown at Bell Laboratories.

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THEORY AND PRACTICE

Many people delight in making a sharp distinction between theory and practical work. The truth of the matter is that the two are so intimately related that such a distinction is difficult to draw and almost meaningless. Theory is not much good unless it will stand up in practice, and practice or production without good theory is likely to be wasteful and ineffective.

The foregoing comes into quality control because many a "practical man"—executive, production foreman or plant engineer—refers to the quality control man as a theorist and likes to proudly call his own work "practical."

I think that we in quality control sometimes need to take the offensive. Witness the following: At a company recently we were having a meeting on rubber standards and specifications. During the discussion the vice-president several times referred to the SQC viewpoint as "your theories." At the close of the meeting, after our decisions were reached I said I wanted to say a few words. I said to him, "You have several times referred to 'your theories' as something apart from practical production, so I would like to say something on this. Here you see a frequency distribution of nearly 2500 measurements on the thickness of rubber, which we have been using recently with no trouble. Now this frequency distribution is not 'theory' to me, but is 'facts.' There is practice; it is what we are using. To my way of thinking, your 'specifications' might be called 'theory,' because, as you can see, about 52 percent of the rubber we have been using satisfactorily is above the upper specification! In this case the frequency distribution is practice and the specifications are theory if anything is."

We have got to sell SQC as one of the greatest aids in being "practical." It is perhaps the best tool we have for getting at the facts.

I. W. Burr

OUR COVER

For this month's cover picture we are indebted to Clifford A. Wallace whose article on page 46 describes the function and operation of the gage laboratory at Kodak Camera Works. Shown in the picture is the portable gage bench used by the laboratory to permit on-the-job checking of gages.

Industrial Quality Control

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Principles of Sampling in the Chemical Field*

MARTIN A. BRUMBAUGH

Bristol Laboratories, Syracuse, N. Y.

INTRODUCTION

The subject of this article has received a great deal of attention in recent years. Some of the time-honored procedures of the analytical laboratory have been confirmed by the statistical approach; others, have needed revision. The principal advantage of the statistical approach has been to aid chemists in obtaining a better understanding of the variabilities involved and their relation to test results.

The work that has been done has been more fragmentary than systematic, but there is good reason for this. The size and ramifications of the problem have led many investigators to the conclusion that no set of rules for sampling can be comprehensive enough to cover all cases and at the same time be sufficiently specific to be directly applicable within a plant. What is said in this article conforms to this point of view. I am quite well aware that any statement in the sequel which may appear to be a rule of action is, in fact, nothing more than guidance. Actual practice within a plant will require adjustment to individual conditions.

Although there are few rules of sampling procedure, there is a well defined set of statistical procedures which are applicable to sampling. The purpose of this article is to present to you a statistical approach which can then be used to set up valid sampling procedures for individual cases.

The problem could be attacked by raising five questions:

I. What is a proper universe or lot for sampling?
II. How should those samples be selected?
III. What number of samples should be taken?
IV. How should the samples be treated in the laboratory?
V. What do the chemical results mean in terms of the lot?

Without additional knowledge none of these questions can be answered. This is why generalization is futile.

What is a proper lot for sampling?

For incoming material the shipment received is the only thing available for sampling. But a power station may receive ten cars of coal daily. Usually each car is considered to be a separate lot for sampling. Many other such cases could be cited.

If there is any reason to suspect that the shipment consists of nonhomogeneous sublots, then the sublot should be the lot for sampling. For example, a truck load of vials received by a pharmaceutical manufacturer may contain vials from several different multiple cavity molds. Naturally the quality characteristics of the molds will be different. If the packing cases are well marked, the test samples should be taken separately from the product of each mold. It should be added that for either case it is assumed that it is feasible to take a random sample of the shipment. For the case of sampling sublots, however, a much larger sample will be needed because an additional and sizable source of variability has been included, and the degree of representation of each mold is uncontrolled. An alternative procedure would be to recognize the shipment as stratified and attempt to obtain a sample proportional to the contribution of each mold to the shipment.

Many situations concerning incoming shipments could be discussed. The general principle is to exercise every precaution to know the characteristics of the shipment and to plan the sample accordingly. Less homogeneous shipments require larger samples.

The definition of a lot also comes up in sampling within the plant. For a batch process the batch is the lot, but homogeneity continues to be important in sample size. For continuous processes there are few rules. Some guides can be given. Any change in processing, rate of flow, temperature, new batch of reagent, cleaning, etc., may mean essentially that a new lot is being sampled. Often a day's run can be considered as a lot; in others a week's run may possess sufficient homogeneity to be called a lot. But most commonly there is no distinct lot in the usual sense. Hence, no separate lot judgments can be made. In fact, the shipment of finished product becomes a lot which may or may not contain material consecutively produced. All of this is merely a preface to the conclusion that judgment is required in applying to continuous processing the concept of a lot for sampling purposes.

How should samples be selected?

The general and largely meaningless answer is that every part of the lot should have an equal probability of being included in the sample. In many cases the entire lot is not available at any one time or place or, even though the lot is available for sampling, not all parts are equally accessible. Hence, compromises of the general principle are the usual practice.

A word of caution should be introduced at this point. The fact that complete representativeness is usually not attainable does not give the sampler license to take "any old sample." He should understand clearly that his objective is to submit a sample which will keep to a minimum the probability that the results of analysis will misrepresent the lot.

Further discussion requires separate attention to liquids, solids and gases.

*Presented February 1953 at Rutgers University as a paper in a series "Statistics for Chemists" sponsored jointly by the university and the North Jersey section, ACS. Presented for publication in IQC through the Chemical Division, ASQC.

Liquids. If there is reasonable expectation that the lot is homogeneous, any sample will be like any other. In most cases such expectation is not reasonable, and it is preferable to assume nonhomogeneity and sample accordingly. Only a chemist can advise as to the pattern of stratification to expect in a given solution. In a free flowing liquid the most common practice is to assume vertical stratification. A representative sample must include components from at least the top, middle and bottom. A more viscous liquid must include lateral as well as vertical components.

The question of whether these components are to be kept separate or united is discussed in the next section. Probably the sampler should be instructed to submit separate, labeled samples to the laboratory. The question of compositing (a statistical question) can then be settled by analysts who possess the pertinent information.

Solids. Nonhomogeneity must be assumed, and the pattern will be different for almost any material one might name. A thief and good judgment are required. In general, the thief is inserted diagonally rather than vertically. Standard practice has been set up by such agencies as ASTM, ASA, U. S. Pharmacopoeia, National Formulary, etc.

Gases. If the sample is to be taken from a moving stream a device for trapping and a bleed valve are necessary. If the stream is nonhomogeneous some system of frequent sampling must be devised.

One of the most difficult problems of gas sampling is to obtain a representative sample to determine the bacteria count of the air in a room. A commonly used method is to expose agar-seeded plates and count the colonies of bacteria on the developed plates. But it is well known that the rate of precipitation of bacteria on the plate is related to the humidity of the air. Therefore, plate counts must be quoted in terms of humidity. An alternative method is to trap the air, but this has its pitfalls because of temperature.

Unless a representative sample of a gas can be obtained, laboratory analysis is unwarranted.

What number of samples should be taken?
How should the samples be treated in the laboratory?
What do the chemical results mean in terms of the lot?

The first question as stated has no answer. It merely raises a second question: "To do what?" The "what" consists of two things; (a) the precision required in the result, and (b) the risk one is willing to absorb of obtaining an incorrect result. One might rephrase the question as follows: "What number of samples must be taken in order to obtain a result which will fall within 2 percent of the correct value 95 percent of the time?" The precision and risk are now defined. However, the information provided is not yet sufficient to answer the question. The number of samples which must be tested will depend upon the precision of the testing procedure as well as a stated precision of results and a risk of error.

The contribution of the statistician consists in defining and controlling the precision of test procedures. Hence, the major emphasis falls on this phase of the subject. Perhaps the most common practice in the analytical laboratory is to run duplicate determinations on a single sample and report the average as the content of the material sampled. In case the result does not conform to previous testing or to a specification, additional testing will ordinarily be done, but ultimately a decision will be made on the material either after the first test or some subsequent one. With or without additional testing the decision may be either right or wrong. Statistics cannot alter this basic fact; but the use of statistics can provide information as to how a given test should be run in order to keep the risks of a wrong decision within previously determined limits.

The major consideration is variability. Variability is measured by the standard deviation, σ, which takes into account the differences among two or more determinations, or the range, R, which is a measure of the difference between the largest and smallest of two or more determinations.

The ultimate goal, as stated, is to conduct the sampling procedure so that an answer will be obtained to the question, "Is this lot of material satisfactory?" However, there are many intermediate considerations which require attention. Therefore, one must approach the goal through a series of steps.

LABORATORY VARIABILITY

Let us assume that a test is to be run on new material. The analytical procedure has been set up and is well understood by the analysts. The requirement is that the test provide the correct result within $\pm$ 2 percent in 95 percent of the tests. How many replicates shall be run? To answer this question the laboratory variability must be determined.

As a specific example, a sample of the material properly composited should be divided into at least ten parts and distributed to the analysts to be run in duplicate. The results of a series of such analyses are shown in Table I. From these data the laboratory variability σ_0 can be determined as

$$\sigma_0 = \overline{R}/d_2$$
$$= 0.75/1.128$$
$$= 0.665$$

To determine the number of replicates from Fig. 1 it is necessary to convert this laboratory variability into a relative standard deviation,

$$V = \sigma_0/40 = 0.665/40 = 1.66\%$$

TABLE I—Data for Determining Laboratory Variability

Aliquot No.	Laboratory Determination 1	2	Range
1	40.6	38.8	1.8
2	41.0	40.6	.4
3	39.9	40.4	.5
4	40.2	39.7	.5
5	41.1	41.6	.5
6	41.8	42.3	.5
7	37.8	38.4	.6
8	39.9	38.9	1.0
9	40.7	41.5	.8
10	38.8	37.9	.9
			$\Sigma R = 7.5$
			$\overline{R} = 0.75$

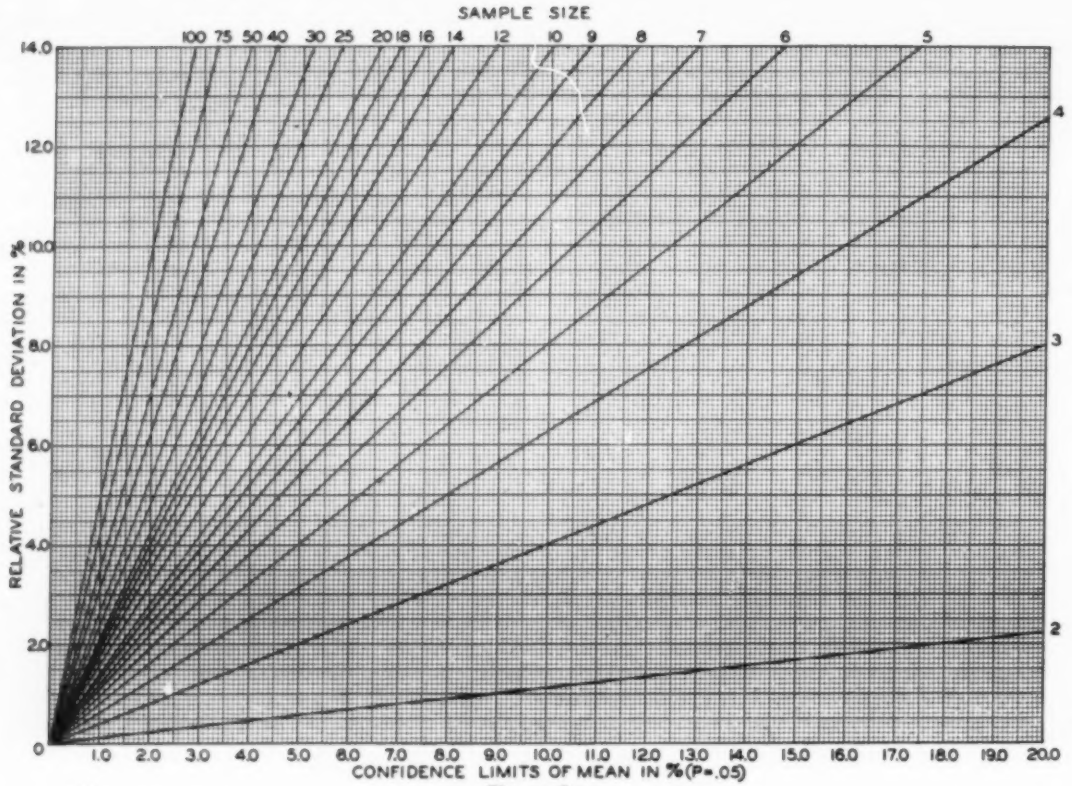

Figure 1

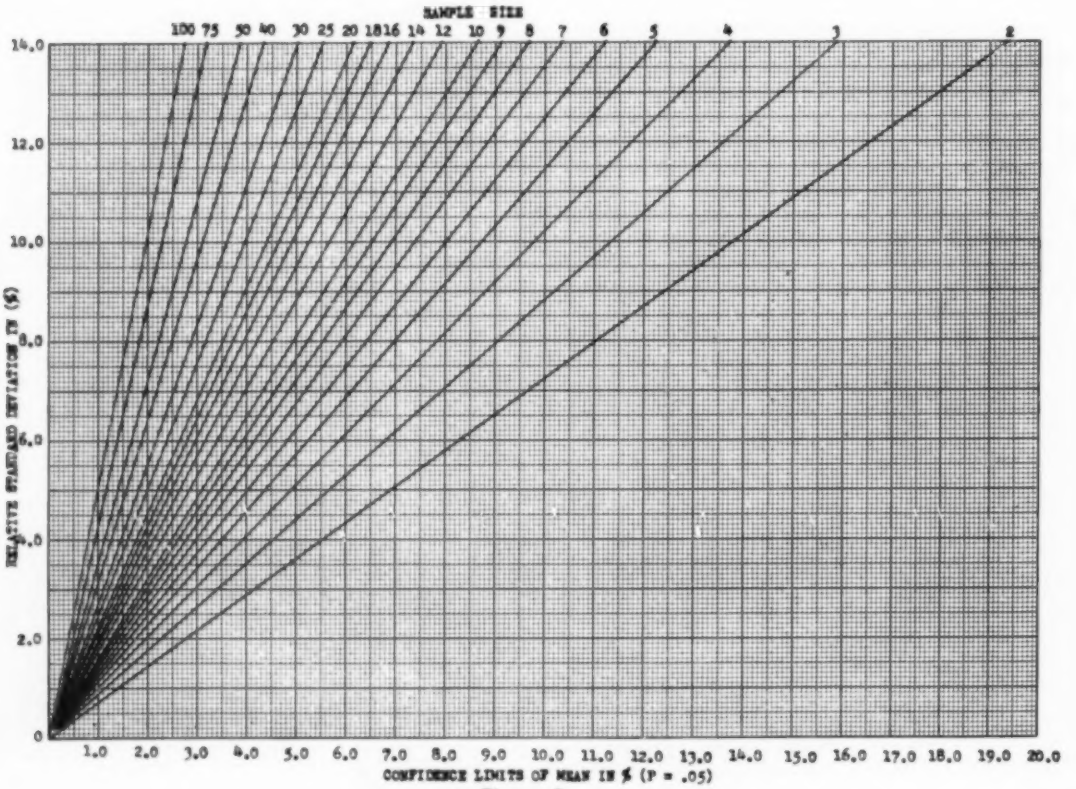

Figure 2

where the constant 40 is a standard value and not the average of this sample. The number of replicates can now be obtained by entering Fig. 1 at the relative standard deviation V = 1.66 percent, moving to the intersection with the confidence limit line C.L. = 2 percent, and choosing the ray just above this intersection. From Fig. 1 it is seen that the number of replicates for this example is six.

This means that by running six replicate tests on a properly composited sample of this material one can expect that in 19 out of 20 cases the average of the six results ± 2 percent will include the correct value.

It is of interest to check this result by the usual formula for confidence limits: *

$$\begin{aligned} \text{C.L.} &= \pm t\,\sigma_{\bar{x}} = t\,\sigma/\sqrt{n} \\ &= \pm 2.57 \times 0.665\ /\sqrt{6} \\ &= \pm 2.57 \times 0.271 \\ &= \pm 0.70 \end{aligned}$$

At an average level of 40 this is 0.70/40 = 1.75 percent.

After additional testing of this material has established the standard deviation of the laboratory variability, it may be possible to reduce the amount of replication. To determine this we use the ray graph of Fig. 2. This one differs from Fig. 1 in that the number of samples is determined from a table of areas of the normal curve. The assumption back of this is that the standard deviation of testing will not change from the established value.

Suppose that the standard deviation of 0.665 proved to be a universe value. Then we would enter Fig. 2 with V = 0.665/40 = 0.0166 or 1.7 percent and a C.L. = 2 percent. The intersection of these values on the graph is just below the three ray, so three replicates will be sufficient.

The use of these ray graphs, or a formula for confidence limits, requires that the distribution of tests be normal and continue in control. The requirement of normality may not be precisely met in many chemical tests, but the departure is seldom so radical that the assumption of normality must be abandoned. The requirement that tests continue in control means that not only must they be checked initially but also as testing continues. This can be done with the usual control chart procedure. Charts for averages and ranges can be set up from the original record and the frame projected for current plotting of test results. A point out of control on the range chart must be investigated, because it means that something has occurred in the laboratory which, if repeated, will lead to revision of the testing program. Points out of control on the average chart might result from a shift in the average level, bias in the testing procedure, or carelessness. Whatever the circumstance, points out of control on the average chart will nullify the objective of predicting lot quality within stated limits. If samples of standard material are available, a chart of daily analyses of the standard should be maintained as a reference for both accuracy and precision.

*The value of 2.57 for t was read from a t table with five degrees of freedom.

Perhaps we should pause at this point to consider the meaning of the laboratory variance. It is the net effect of the combined action of analysts, equipment, temperature, humidity, reagents, standards, etc. Any time that these factors produce excessive variability they should be investigated. The standard procedure for doing this is variance analysis. For example, we might suspect that some laboratory equipment was causing variability. To test this we might set up duplicate equipments and have an analyst carry out identical procedures on each equipment. But the differences which appear are not necessarily due to equipment; the analyst may have operated them differently. Therefore it would be preferable to use three equipments and three analysts in the following design:

A_1			A_2			A_3		
E_1	E_2	E_3	E_1	E_2	E_3	E_1	E_2	E_3
- -	- -	- -	- -	- -	- -	- -	- -	- -
- -	- -	- -	- -	- -	- -	- -	- -	- -

From analysis of data so designed one can get the following information:

a) Differences in analysts free from the effect of equipment.

b) Differences in equipments free from the effect of analysts.

c) Any interaction between equipments and analysts; e.g., a tendency for Analyst 2 to obtain low results on Equipment 1.

d) The size of the error variance from the replicates. If this tends to be large compared with the other variances, it means that other causes of variability (e.g., humidity) which appear at random in these results are more important than analyst or equipment difference. This is the signal for a differently designed experiment intended to catalog these floating causes of variability.

e) Components of variance to determine which is the largest and therefore the one to improve first.

These methods of segregating and defining the separate causes of laboratory variability can be used to reduce such variability. The plea has usually been that the laboratory has too much routine work to spend time uncovering these sources of variability. Slight study of the ray graphs will quickly indicate to any laboratory manager what can be gained by reducing laboratory variability.

SAMPLING VARIABILITY

We turn now to the next step in the major development. Earlier in this article considerable attention was given to the fact that samples from different parts of chemical materials will have different proportions of ingredients. When samples are composited prior to testing, these differences are cancelled. In many cases this may be the proper procedure after investigation, but it is almost always a dangerous procedure before investigation. From the practical point of view the nonhomogeneity within a lot may be unimportant if all

of it is used at once. Under other circumstances small parts of the lot may be used and the lack of homogeneity may be a major factor. But regardless of the practical situation, within-lot variability is important in a testing program and knowledge of it is indispensable in setting up methods of securing samples.

As an example reconsider the set of test data given in Table I. Suppose that these were really duplicate analyses of ten samples from a lot. Two sources of variability, laboratory (within-sample) and between-sample, would be present and a variance analysis would be needed to assess their separate importance. The problem is set up by rearranging the data of Table I as shown in Table II. Then using the following notation

$$n = \text{number of samples} = 10$$

$$r = \text{number of replicates} = 2$$

$$\sigma_0^2 = \text{variance within samples}$$

$$\sigma_1^2 = \text{variance between samples}$$

the results are summarized in Table III.

Using these results it is seen that the laboratory variability is obtained directly from the term σ_0^2. In this example $\sigma_0^2 = 0.40$ hence $\sigma_0 = 0.632$ which is quite close to the value 0.665 obtained from ranges. The variability due to samples can be obtained from the first component in Table III

$$r\,\sigma_1^2 + \sigma_0^2 = 1.44$$

$$2\,\sigma_1^2 = 1.44 - 0.40$$

$$\sigma_1^2 = 0.52$$

The combined variance due to both laboratory and samples is

$$\sigma_{L+S}^2 = \sigma_L^2 + \sigma_S^2$$

$$= 0.40 + 0.52$$

$$= 0.92$$

Therefore

$$\sigma_{L+S} = 0.96$$

We are ready to answer a second question: "If a single sample is taken from this lot, how many replicates will be necessary in order to predict the correct content within ± 2 percent?" Figure 2 can be used to answer this question.

$$V = 0.96/40 = 2.4\%$$

$$\text{C.L.} = 2\%$$

Hence from the graph

$$n = 6$$

This means that an average of six analyses will be necessary in order to have 95 percent assurance that the true content of the lot will not vary from this average by more than ± 2 percent.

Compositing and Cost

Let us investigate a collateral question: "Is there some best method of running these six analyses from the standpoint of laboratory costs?" Suppose that we

TABLE II—Variance Analysis Data—One Factor with Replication

		Sample Nos. 1	2	3	4	5	6	7	8	9	10	Grand Total
Replicates	1	40.6	41.0	39.9	40.2	41.1	41.8	37.8	39.9	40.7	38.8	
	2	38.8	40.6	40.4	39.7	41.6	42.3	38.4	38.9	41.5	37.9	
Totals		79.4	81.6	80.3	79.9	82.7	84.1	76.2	78.8	82.2	76.7	802.1

1. Correction Factor: $802.1^2/20 = 32{,}168$
2. Between Samples: $79.4^2 + \ldots + 76.7^2/2 = 32{,}181$
3. Within Samples: $40.6^2 + \ldots + 37.9^2 = 32{,}185$

TABLE III—Variance Analysis Summary—One Factor with Replication

Source	Variance Components	Deg. of Freedom	Sum of Squares*	Mean Squares
Between samples	$r\sigma_1^2 + \sigma_0^2$	$n - 1 = 9$	(2) − (1) = 13	1.44
Within Samples	σ_0^2	$n(r - 1) = 10$	(3) − (2) = 4	0.40
Totals		$nr - 1 = 19$	(3) − (1) = 17	

*Nos. 1, 2 and 3 refer to values in Table II.

obtain from the cost records two separate sets of charges

(a) the cost of running replicates on the same sample, and

(b) the cost of obtaining samples and preparing composites.

Table IV contains a hypothetical set of such costs, and Table V contains costs of running a set of analyses on composite samples. For example, to run four replicates on a composite sample prepared from three individual samples would cost $4.30.

The variability side of the problem is as follows:

$$\sigma_{L+S}^2 = \sigma_L^2 + \sigma_S^2$$

If compositing is to be done, then the following notation can be used:

n = the number of individual samples in a composite sample

r = the number of replicates run on a composite sample

m = the number of composite samples

Then the variance of the average of all tests will be

$$\sigma^2 = \frac{1}{m}\left(\frac{\sigma_L^2}{r} + \frac{\sigma_S^2}{n}\right)$$

The precision requirement was stated in our example as ± 2 percent or ± 0.8 around 40 with 95 percent confidence of correct decision. Then

$$1.96\,\sigma = 0.8$$

$$3.84\,\sigma^2 = 0.64$$

$$\sigma^2 = 0.1665$$

Therefore

$$0.1665 = \frac{1}{m}\left(\frac{\sigma_L^2}{r} + \frac{\sigma_S^2}{n}\right)$$

Substituting the values of the variances gives

$$m = \frac{1}{0.1665}\left(\frac{0.40}{r} + \frac{0.52}{n}\right)$$

from which

$$m = \frac{2.40}{r} + \frac{3.12}{n} \qquad (1)$$

From this formula and Table V a listing of costs can be prepared as shown in Table VI.

The minimum cost, $6.16, occurs when four individual samples are compos ed to give a single composite on which six replicate tests are made. This is, of course, the procedure most commonly employed. Costwise it is best, provided no information concerning the within-lot variability is needed. If the average of six tests of this sample gives sufficient information, the only thing learned from the cost analysis is the fact that four individual samples is the least number that should be used in preparing the composite. On the other hand, if verification of homogeneity of the lot is required, the lowest cost plan is to take six samples from the lot, prepare two composites of three samples each and run three replicate tests on each composite sample. The cost of this procedure will be $6.90.

The compositing of three individual samples conceals the extremes of within-lot variability. To obtain full information on this subject, the only procedure available is the first entry of Table VI, i.e., take six samples and analyze each one separately. In this case the precision requirement will be met by doing one test on each sample and the cost will be $7.20.

This is a relatively simple example, but the cost procedure employed is generally applicable. In applying this procedure, however, the costs in Table IV, which are fictitious, should not be used. For a discussion of this method refer to the article by B. H. Lloyd, "The Statistical Approach to Bulk Sampling Problems," *Industrial Quality Control*, Vol. IX, No. 6, May 1953, p. 113.

TABLE IV—Cost in Dollars of Preparing Samples and Running Replicates

r	Cost	n	Cost
1	$1.00	1	$0.20
2	1.90	2	0.43
3	2.80	3	0.65
4	3.65	4	0.86
5	4.48	5	1.06
6	5.30	6	1.25
7	6.10	7	1.43
8	6.86	8	1.60
9	7.56	9	1.75
10	8.21	10	1.89

TABLE V—Cost in Dollars of Running r Replicates on a Single Composite Sample Made from n Individual Samples

r	n = 1	2	3	4	5	6	7	8	9	10
1	1.20	1.43	1.65	1.86	2.06	2.25	2.43	2.60	2.75	2.89
2	2.10	2.33	2.55	2.76	2.96	3.15	3.33	3.50	3.65	3.79
3	3.00	3.23	3.45	3.66	3.86	4.05	4.23	4.40	4.55	4.69
4	3.85	4.08	4.30	4.51	4.71	4.90	5.08	5.25	5.40	5.54
5	4.68	4.91	5.13	5.34	5.54	5.73	5.91	6.08	6.23	6.37
6	5.50	5.73	5.95	6.16	6.36	6.55	6.73	6.90	7.05	7.19
7	6.30	6.53	6.75	6.96	7.16	7.35	7.53	7.70	7.85	7.99
8	7.06	7.29	7.51	7.72	7.92	8.11	8.29	8.46	8.61	8.75
9	7.76	7.99	8.21	8.42	8.62	8.81	8.99	9.16	9.31	9.45
10	8.41	8.64	8.86	9.07	9.27	9.46	9.64	9.81	9.96	10.10

Precision

In the preceding example the precision requirement was established in advance and the entire discussion was geared to meeting this requirement. Let us now consider another situation in which the precision requirement (width of the confidence band) is not predetermined. In fact, Figs. 1 and 2 perhaps have a more general application in answering the question: "If I perform n analyses, what precision can I expect?"

For example, suppose that four analyses are performed on a sample of a new material and the results are as follows:

Test	Percent Recovery
1	65.6
2	69.3
3	62.9
4	66.2

$$\bar{X} = 66.0$$

$$\sigma = 2.63$$

$$\sigma/\bar{X} = 0.0398 \text{ or } 4\%$$

According to Fig. 1 we can say, with the expectation of being correct 19 out of 20 times, that the recovery of the lot lies at $66 \pm (6.4 \times 0.66)$ percent or 66 ± 4.2 percent. If this estimate is not close enough, the remedy lies in doing more replicates.

TABLE VI—Values of m from Eq. (1) and Corresponding Cost in Dollars

r	n = 1		2		3		4		5	
1	5.52 (6)	*7.20*	3.96 (4)	*	. . .		. . .		. . .	
2	4.32 (4)	*8.40*	2.76 (3)	*6.99*	2.24 (3)	*7.65*	. . .		. . .	
3	3.94 (4)	*12.00*	2.36 (3)	*9.69*	1.84 (2)	*6.90*	1.58 (2)	*7.36*	1.42 (2)	*7.72*
4	3.72 (4)	*15.40*	2.16 (2)	*8.16*	1.64 (2)	*8.60*	1.38 (2)	*9.02*	1.22 (1)	*
5	3.60 (4)	*18.72*	2.04 (2)	*9.82*	1.52 (2)	*10.26*	1.26 (1)	*	. . .	
6	3.52 (4)	*22.00*	1.96 (2)	*11.46*	1.44 (2)	*11.90*	1.18 (1)	*6.16*	. . .	

*The number of analyses does not meet the precision requirement.

Let us suppose that repeated testing of this material has shown that the laboratory variability is 4 percent. We are then entitled to expect the precision of the estimate to be expressed in Fig. 2, from which the precision turns out to be 4 percent. Estimates should give within 2.64 percent of the true average recovery 95 percent of the time.

There is a further consideration on this matter of precision. When both laboratory and sampling variability are to be taken into account, a variance analysis will be necessary initially in order to determine the combined σ. Once this is established, the precision of any combination of samples and replicates can be determined from Fig. 2 in exactly the same manner as in the preceding application. However, it may be desirable to look further at the two sources of variability involved.

Suppose that we have the following:

$$\bar{X} = 100$$

$$\sigma_L^2 = 2$$

$$\sigma_S^2 = 10$$

$$\sigma_{L,S}^2 = \sigma_L^2 + \sigma_S^2$$

$$= 12$$

$$\sigma = 3.48$$

If one analysis of a single sample were made, the confidence band would be

$$\text{C.L.} = \pm 1.96 \times 3.48 = \pm 6.8$$

By running one replicate on each of five samples, the variance of the average of the five tests would be

$$\sigma^2 = \sigma_L^2 + \frac{\sigma_S^2}{5} = 2 + 2 = 4$$

$$\sigma = 2$$

so the variability in the individual tests would be

$$\sigma_{\text{ind.}} = 2\sqrt{5} = 4.47$$

and the confidence band (Fig. 2) would be $\pm$ 3.9. On the other hand if five replicates were run on a single sample, then

$$\sigma^2 = \frac{\sigma_L^2}{5} + \sigma_S^2 = 0.4 + 10$$

$$= 10.4$$

$$\sigma = 3.21$$

$$\sigma_{\text{ind.}} = 3.21\sqrt{5} = 7.18$$

and the confidence band (Fig. 2) would be $\pm$ 6.3.

As a third case, if five replicates were run on each of five samples, the variance would be

$$\sigma^2 = \frac{\frac{\sigma_L^2}{5} + \sigma_S^2}{5} = \frac{10 + 0.4}{5} = 2.08$$

$$\sigma_{\text{ind.}} = 1.44\sqrt{25} = 7.2$$

and the confidence band (Fig. 2) would be $\pm$ 2.9.

These results can be summarized to indicate the proper procedure in the laboratory. By running five replicates on a single sample the precision was increased very little—a reduction of the confidence band from 6.8 to 6.3. By running single determinations on five samples the confidence band was reduced from 6.8 to 3.9. Further, it should be noted that running five replicates on each of five samples reduced the confidence band from 3.9 to 2.9. Thus, five times as much testing has narrowed the confidence band by about 25 percent. If the material is nonhomogeneous and the test is poor, then precision requirements may force a large number of tests. But the cost factor alone would dictate action to improve process uniformity and improvement of analytical procedure. In general, such action should be considered when as many as ten laboratory determinations per lot are required.

In this example the sampling variability was greater than the laboratory variability and the greater gain in precision came from analyzing more samples. If the initial investigation showed the reverse situation, the greater gain would come from more replicate analyses. Usually a small sampling error is the signal to composite and concentrate entirely on control of laboratory error.

In the previous paragraph the case was mentioned of improving the laboratory technique to meet a precision requirement. Let us suppose that the precision requirement is $\pm$ 2 percent and that the average value is 50, then the laboratory supervisor is entitled to ask, "If I run three replicates, what variability standard must they meet?"

The answer can be given by the use of Fig. 2. The 2 percent line on the horizontal axis intersects the three ray at a point which reads 1.75 percent on the vertical scale. This means that the standard deviation of individuals must not exceed $0.0175 \times 50 = 0.875$. It is easier to deal with ranges, hence, the next step is to transfer from σ to range in the usual way. In this case R for three replicates must not exceed $d_2\sigma$ or $1.693 \times 0.875 = 1.48$. I would, therefore, say to the laboratory supervisor: "The average range of about 20 sets of triplicate determinations must not exceed 1.5, the 20 averages must be around 50, and I would suggest as your best device the maintenance of average and range control charts, because I cannot guarantee what your technicians are capable of doing in the future unless both charts are in use and show control." In fact, continuation of these charts is his best method of verifying future conformance to this standard. Likewise, a trend in ranges as well as out-of-control points are the signal that something is different and requires attention.

LOT VARIABILITY

We return now to the major outline. Laboratory variability and sampling variability have been discussed. The major purpose of testing is to detect lot variability. However, the internal variability is always present and must be managed, if lot-to-lot determinations are to have meaning. Whether we are considering new material or studying an established testing procedure, the first step is to ascertain the amount of variability assignable to each of the three sources—lots, samples, laboratory. Table VII contains data representing two replicates on each of ten samples from two lots. Lot I is a reproduction of the data used earlier in this article. Lot II represents new data. Using the following notation

TABLE VII—Variance Analysis Data—Lot-to-Lot Variability

Sample No.	Lot I Replicates		Lot II Replicates	
1	40.6	38.8	41.3	42.2
2	41.0	40.6	42.0	41.7
3	39.9	40.4	40.9	42.6
4	40.2	39.7	40.6	39.7
5	41.1	41.6	43.1	42.6
6	41.8	42.3	41.8	41.9
7	37.8	38.4	42.3	41.5
8	39.9	38.9	41.6	42.8
9	40.7	41.5	43.0	42.3
10	38.8	37.9	41.1	42.2

TABLE VIII—Variance Analysis Summary—Lot-to-Lot Variability

Source	Variance Components	Deg. of Freedom	Sum of Squares	Mean Squares
Between Lots	$nr\,\sigma_2^2 + r\,\sigma_1^2 + \sigma_0^2$	1	31.15	31.15
Between Samples	$r\,\sigma_1^2 + \sigma_0^2$	18	38.72	2.15
Between Replicates	σ_0^2	20	7.82	0.39
Totals		39	77.69	

TABLE IX—Formulas and Calculations for Sampling Plan

Definitions:

W_0 = desired average of the lot
= 40

W_1 = lower tolerance for lot average
= 39.2

W_2 = upper tolerance for lot average
= 40.8

α = risk of rejecting a lot whose average is W_0
= .05

β = risk of accepting a lot whose average is beyond W_1 or W_2
= .05

$t(\alpha)$ $t(\beta)$ = value of t on a one tailed distribution of the normal curve.

σ = standard deviation of combined testing, sampling and lot variability
= 1.64

To be determined:

n = number of tests which must be run

$\bar{X}_1$ = lower acceptable average for the tests

$\bar{X}_2$ = upper acceptable average for the tests

Equations:

$$n = \sigma^2 \left[t(\alpha/2) + t(\beta) \right]^2 / (W_0 - W_1)^2 \quad (2)$$

$$\bar{X}_1 = \left[t(\alpha/2) W_1 + t(\beta) W_0 \right] / \left[t(\alpha/2) + t(\beta) \right] \quad (3)$$

$$\bar{X}_2 = \left[t(\alpha/2) W_2 + t(\beta) W_0 \right] / \left[t(\alpha/2) + t(\beta) \right] \quad (4)$$

Calculations:

$n = (1.64)^2 (1.96 + 1.645)^2 / (40 - 39.2)^2$
$= 2.7 \times 13.00 / 0.64$
$= 35.1 / 0.64$
$= 55$

$\bar{X}_1 = \left[(1.96 \times 39.8) + (1.645 \times 40) \right] / (1.96 + 1.645)$
$= (78.01 + 65.80) / 3.605$
$= 143.81 / 3.605$
$= 39.89$

$\bar{X}_2 = 40.11$ (symmetrical)

N = the number of lots = 2

n = the number of samples = 10

r = the number of replicates = 2

the results are summarized in Table VIII. The components of variance can be obtained from this table as before.

The replicate variance is obtained directly as $\sigma_0^2 = 0.39$. The sample variance is then

$$r\,\sigma_1^2 + \sigma_0^2 = 2.15$$
$$2\,\sigma_1^2 = 2.15 - 0.39$$
$$\sigma_1^2 = 0.88$$

and the lot variance is

$$nr\,\sigma_2^2 + r\,\sigma_1^2 + \sigma_0^2 = 31.15$$
$$20\,\sigma_2^2 = 31.15 - 0.88 - 0.39$$
$$\sigma_2^2 = 1.43$$

The total variance is

$$\sigma^2 = \sigma_2^2 + \sigma_1^2 + \sigma_0^2 = 1.43 + 0.88 + 0.39$$
$$= 2.70$$

hence

$$\sigma = 1.64.$$

We can now compare the two lots as to internal variability. The variance of replicates was 0.40 for the first lot and is 0.39 for the two combined. From this we can conclude that the test variability is fairly well defined. The sampling variability is somewhat greater in the second lot, an increase from 0.52 in the first lot to 0.88 in the combined lots. This suggests that the sampling procedure was not as well conducted in the second lot or that this lot is less homogeneous. Further analysis of additional lots would be necessary to determine whether any amendment would be required in the testing program already established.

The next step is to define a testing program which will include lot-to-lot variability. From Fig. 2 we can determine that to hold the variability within ± 2 percent when $\sigma/\bar{X}' = 1.64/40 = 4.1$ percent, the minimum number of tests is 18.

This is an expensive program which would lead the laboratory supervisor to search for relief. The first step would be to discover whether the ± 2 percent precision requirement could be relaxed. If not, there is one avenue of escape, provided the within-lot variability can be abandoned. By compositing samples, this source of variability can be eliminated. The total variance would then be 1.82 and σ would be 1.35. The number of replicates could be reduced to 12. If the within-lot variability must be measured in part at least, an analysis in terms of cost such as that previously made should be undertaken to discover the least cost program which will meet both precision requirements—overall and within-lot definition.

There is one general principle that cuts across all of the preceding discussion which might have been stated earlier. If the test variability exceeds the sampling variability, there is little to be gained by attempting to measure the sampling variability. One might as well composite samples. Again, if both the test and sampling

variability exceed the lot-to-lot variability, it is extremely expensive to run enough tests to be able to discriminate between good and bad lots. It is almost always better to spend money doing something about the test.

ERRORS OF THE FIRST AND SECOND KIND

Thus far emphasis has been concentrated on what is called the error of the first kind with no mention of the error of the second kind; i.e., in stating precision requirements we have uniformly quoted a 5 percent risk of calling a lot outside of tolerance or specification when in fact the lot is inside of specification. The thing which is undefined is the risk that a lot which is really outside of specification will be accepted. The language of acceptance and rejection of material received from a vendor has been used in the preceding sentence because the technique presented next is used most frequently in that area of testing. However the method is equally valid and valuable for testing in-process material as well as finished product.

The plan which is ordinarily used is not in conflict with what has gone before, but adds the new element of defining and controlling errors of the second kind. An exposition of the theoretical argument, which is quite lengthy and slightly involved, is unnecessary. A listing of the information which must be settled in advance and that which must be obtained from experience with the particular test in question will be presented (Table IX). Values from the major example of previous sections have been used and known values have been listed along with the definitions.

The three equations to be solved (2), (3), and (4) are presented without proof. The basis for these can be found in *Industrial Quality Control*, March, 1947 p. 12, "Acceptance Sampling Inspection by Variables," Paul C. Clifford.

This is obviously not a practical plan. Having obtained these results, one would immediately set about spreading the precision requirement, or, if that were not feasible, reducing the testing and sampling variability. The latter can be eliminated by compositing a large enough number of individual samples. The resulting standard deviation is for this example 1.35. With this change the number of tests would reduce to 37, but this is still too large for practical work and emphasis must be placed on reducing the variability between lots. This means working with the vendor through your own purchasing department. Although this may in the past have been a sterile approach in the experience of some, it is really surprising what your purchasing agent can do for you, when armed with the sort of information which the statistician could provide in this case.

Controlling error of the second kind with small samples is troublesome. Mostly, this phase of a testing program is neglected. The real difficulty in this case is a precision requirement with a value less than σ. This greatly increases the risk of accepting poor material, unless the multiple tests indicated in this example are run.

Again a caution—a tight specification without adequate testing increases the risk of accepting poor material without being aware of the situation.

SUMMARY

The gist of this paper is: (1) get a usable definition of a lot for sampling purposes; (2) get samples which will represent the characteristics of the lot; (3) get a clear statement of what information is wanted concerning the lot, particularly the precision requirement; (4) plan the test procedure with two things in mind, (a) to meet the precision requirement if stated or to define it if left to your discretion, and (b) to operate the test so that the results can be interpreted; (5) to state results in terms of the quality of the lot and not so that the interpretation of the meaning of the test results is placed in the hands of persons who have no knowledge of how the test was conducted.

Some Aspects of Experimental Design

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In the space available here it is not possible to discuss in a very useful fashion more than a limited area of the broad problem of planning and designing experiments. I shall attempt to discuss in a general way certain aspects of the problem that are of particular interest to the statistician. My plan is to consider in some detail a simple illustrative situation, raising in connection with it certain questions that seem to be representative of those which arise in the planning of most experiments.

Suppose that we are considering the purchase of a machine or machines to perform some manufacturing operation, and that there are two producers of machines designed for the purpose at hand. Our broad problem is to decide which producer to patronize. We shall assume that a point has been reached where the decision hinges on the answer to a question of the following form: Which producer's machines make the values of X larger?

The variable X is some continuous quality characteristic of items turned out by the machines. It is proposed to answer this question by experimentation, and we have now to consider the problem of planning a "good" experiment for the purpose.

The first point to be noticed is that the question as stated is not sufficiently specific. This is generally the case. The question which originally suggests experimentation is usually one which is too general or imprecise to be answered experimentally. The first problem and the one with which most of this discussion is concerned, is that of stating a question which can be answered experimentally and which at the same time is worth answering.

A brief consideration of the situation will indicate the lines along which the question has to be modified. We probably know that the values of X in a series of items produced by one of these machines vary appreciably among themselves, and that a similar series from another

machine of the other (or even the same) producer would yield X-values which also varied and overlapped, to some extent, those in the first series. If we did not know or at least suspect that this were true we should probably not be considering an experiment. The word "larger" in the original question must mean "larger in some average sense." Our interpretation of this is that in some way as yet unspecified there are two frequency distributions (one for each producer) involved and what we really want to know is which of these two distributions has the larger mean. The original question implies, as does our discussion up to this point, that the variabilities in the two frequency distributions are not pertinent to the decision. We shall not concern ourselves with just how this viewpoint might have come about. It will be necessary for us to consider these variabilities later, but not as part of the question we are attempting to formulate.

We must now turn our attention to a more precise description of the frequency distributions which we have mentioned. Several preliminary remarks are in order:

1. The frequency distributions about which it is useful to know will in this case and in general be such that they can only be investigated partially, i.e., on a sampling basis.
2. In the present state of our knowledge we only know how to "answer" questions about frequency distributions on the basis of samples from them when the samples are random. (N. B. In this discussion a question about a frequency distribution is "answered" only if some precise statement of the probability with which the answer is correct can be made also.)
3. Hence our experiment must be such that the data it provides constitute random samples from frequency distributions which are pertinent.

Most of the statistician's problems in connection with planning experiments result from this state of affairs. For example, the frequency distributions of interest in this case are presumably those which would be generated by letting each of the two types of machine turn out a large number of items under the conditions in which they are to be used, determining X for each item, and arranging the values obtained into frequency distributions. In order to "answer" questions about these frequency distributions our experiment must represent a random sample of whatever we define to be "the conditions in which they are to be used." Such a requirement can almost never be completely satisfied in practice.

For example the experiment has to be conducted in a relatively short time interval and it is difficult to see how any reasonable time interval can be made to include an anywise random sample of the conditions of ordinary routine operation. Perhaps the experiment is planned for the month of January. It is likely that many of the operating conditions are different in January than in July, say. We may feel on the basis of our experience and knowledge that the conditions which differ between the two months are unrelated to the behavior of the machines, and that any conclusions about January are applicable to July. This feeling may be quite correct, but the experiment in January neither defends nor refutes it. It must stand on extra-experimental evidence. In nearly all experiments there will be an inferential step between the question which the experiment can "answer" and the question which we would like to "answer" which cannot be made rigorous in a statistical sense. In practice we can only attempt to make this step as small as practicable.

Let us assume now that the necessary decisions have been made about the conditions under which the experiment is going to be conducted, and turn our attention more particularly to the actual experimental material. Consider first the machines to be used. We can illustrate the points we have in mind here most easily by distinguishing two cases within our illustrative situation.

In the one case we assume that only one machine is to be purchased and that we are not likely to have to replace it for a long time. We assume further that the machine purchased will be one of two available for experimentation, one from each producer. In the other case we suppose that a relatively large number of machines will be purchased without further experimentation from one producer picked on the basis of this experiment. We assume also in this case that just one machine from each producer is available for test.

The difference between the two cases implies a corresponding difference between the frequency distributions which are of primary interest. There are first the two distributions that would be generated by the two machines at hand under the conditions of the experiment. Let A denote the mean of the one of these distributions generated by the first producer's machine and B the mean of the other. In the first case our question refers to A and B. Now we can think of distributions similar to the two just mentioned which would be generated by other machines supplied by each of the two producers. For each producer there is a frequency distribution of these machine means which itself has a mean. Denote these means of machine means by A′ and B′ for the first and second producer respectively. In the second case our question refers to A′ and B′. Any information which the experiment furnishes about A and B is useful in this case only insofar as A and B can provide information about A′ and B′.

We can "answer" questions about A and B experimentally no matter how the two machines at hand were selected from the total production of the two producers. In order to "answer" questions about A′ and B′ the two quantities A and B must be random samples from the distributions defining A′ and B′. The two machines used in the experiment must represent a random selection of the machines made by each of the two producers. (There will still in general be some difficulty about "answering" questions concerning A′ and B′ unless we know or can estimate the variability in the distributions defining them. This difficulty is irrelevant to the issue here.) In summary, the importance of randomness in the selection of the machines for test depends entirely upon the situation. Many experiments fail because a mistake is made similar to that of testing a demonstration (non-random) model from each producer in order to "answer" a question about A′ and B′.

For the balance of this discussion let us assume that we are in the first situation; i.e., interested only in the values of A and B. An experiment involving the two machines at hand is pertinent and a decision about the general conditions under which the

experiment is to be conducted has been made. There remains to be decided just what experimental units are to be used and how they will be distributed to the two machines.

For simplicity let us assume that the raw material for the operation in question enters the machine in the form of a 1-ft bar. Suppose further that it is received in the form of bars twice this long and that the immediately preceding operation is just that of cutting the 2-ft lengths in half. In a broad way the experiment will consist of feeding a series of 1-ft bars into each machine and the experimental data will be measured values of X on the items produced. From the data we will "answer" some questions about the relative sizes of the mean values of X in the two distributions of which the experimental data from the first and second machine are a random sample.

Now in "answering" any question about these means we know that, on the whole, the probability of obtaining a correct answer is a decreasing function of the variability in the distributions defining them. The magnitude of this variability can be influenced to some extent at least by the bars which we admit in the experiment and we have some freedom of choice in this regard. We must at the same time remember, however, that we want our conclusions to apply essentially to all of the bars which will be used in routine operation. The desire to "answer" with a high probability of being correct and at the same time the desire to have the answer apply under wide conditions are not entirely compatible. We have to reach some reasonable compromise.

There are several obvious ways in which we might select bars to use in the experiment and a brief consideration of each of them will be instructive. The simplest procedure would be to just take the desired number of bars out of whatever is the normal stream of supply to machines like the ones under test. If the series of outgoing bars from the preceding cutting operation is in statistical control, then by definition we have a random sample of the normal supply of bars and our experimental conclusions may apply to the whole of the normal supply. If this series is not in control we will be unable to reason with complete statistical validity to the whole of the normal supply. In the latter case we may feel quite safe in assuming that the essential parts of our experimental conclusions apply to the whole supply, but once more this assumption must stand on extra-experimental evidence.

In either case if the inherent variability from one bar to another is large we may require an excessively large number of bars in the experiment to reach some desired probability of correctly "answering" the question asked. We might undertake to pick out of the normal supply of bars a group for experimentation which was as homogeneous as possible with respect to certain features which were felt to be related to the final value of X. In this way we might be able to raise the probability of being correct for a given size of experiment, but the question "answered" by the experiment would doubtless be even further removed from actual routine operation.

There can be no categorical answer to the question of which of the alternatives so far suggested is the better. Each particular situation has its own special properties and the decision has to be made more or less independently in each case. If we do not have a series of bars in statistical control, it is difficult to see how we can ever obtain an even approximately random sample of the entire normal supply; and in such a case we will always be forced to "answer" a question which does not refer (without extra-experimental assumptions) to the exact conditions in which the answer will be applied. In many cases the higher probability of being correct by utilizing a homogeneous non-random selection of the potential experimental material may outweigh the advantages of an entirely random selection even though such could be made.

If our experimental material is not a random sample from some meaningful distribution as in the case of the selection of especially homogeneous bars, it is not obvious just what distribution if any we have sampled randomly. One of the primary functions of objective randomization in the assignment of experimental units (in our case bars) to the treatments (in our case machines) is to assure that the experimental observations do constitute random samples from meaningful distributions.*

Since the raw material originally is received in 2-ft bars, a third possibility for selecting the experimental bars suggests itself. It is quite likely that two bars cut from the same piece are more homogeneous than two bars selected without regard to their origin. We feel instinctively that if in our experiment we allocate the bars in pairs, one to each machine, this homogeneity of bars in the same pair ought to improve the experiment. Hence we may select instead of individual bars, pairs of bars cut from the same piece, allocating one bar of each pair to each machine. In adopting this plan we shift our attention from two frequency distributions, one for each machine, to a single frequency distribution of differences between the X-values, each difference being the X-value for a bar in the first machine minus the X-value for its partner in the second machine. Questions about the means of the two distributions may be reformulated into equivalent questions about the mean of the single distribution. The probability of "answering" questions about this mean correctly may be higher than in the experiments previously proposed.

Such an experiment is called a randomized block experiment. It is the simplest of the formal experimental designs which attempt to take advantage of internal homogeneities of the experimental material or conditions. The statistical analysis of the data from such an experiment is based on assumptions about the frequency distributions involved which are somewhat more restrictive than those required in the previously mentioned experiments.† I should like to point out here that there is a regrettable tendency to overlook the more restrictive nature of the assumptions that are required to validate the analysis of data from more complicated experimental designs.

I have attempted in these remarks to indicate in a broad fashion some of the factors that enter into recognizing clearly just what questions can be "answered" by a proposed experiment. I have intended to emphasize the fact that these questions are usually severely limited and that we must often rely heavily upon extra-experimental evidence to give our experimental conclusions broad applicability.

*For further discussion on this aspect see O. Kempthorne, *Design and Analysis of Experiments*, John Wiley & Sons, New York, 1952.

†For a detailed discussion of these matters see O. Kempthorne, *op cit*, and W. G. Cochran and G. M. Cox, *Experimental Designs*, John Wiley & Sons, New York, 1950.

Effect of Measurement Error On Chemical Process Control*

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A statistical approach to problems arising from a particular type of scientific or industrial endeavor will inevitably lead to the use of statistical techniques which are best adapted to the nature of the problems encountered and the experimental data available. Historically, most broad classes of statistical techniques have been developed in close association with some field of application; for example, the development of correlation techniques in connection with the genetical and, more recently, psychological study of human populations, the development of the principles of experimental design in connection with agricultural research, and the development of statistical quality control in connection with the problems of mass production of manufactured items. Thus as statistical methods are applied to new fields, it becomes necessary to modify existing methods, or develop new methods, so that the peculiar needs of these new fields will best be served. Of course, this is true not only for general areas of application but for every new problem which is to be attacked by statistical methods; however, the problems arising in a particular science or industry frequently have common characteristics which dictate the statistical approach to be used.

The rapid growth in recent years of the use of statistical methods in both chemical research and production has made necessary an examination of the applicability of existing statistical methods in this field, and has already led to new developments directly related to chemical problems. Some things which have been and are being considered are experimental designs more closely related to the particular needs in chemical experimentation, simple estimation techniques for use with the very small numbers of repeated measurements available in most chemical work, and modifications of the assumptions underlying the analysis of variance necessary to increase the applicability of this powerful tool to chemical data. The question of the applicability of statistical quality control techniques to chemical production processes has also arisen, and it is with one particular aspect of this problem that this paper is concerned.

The aim of chemical process control is identical with that of the control of any mechanical process. Both intermediate and final product must meet certain specifications, usually stated in terms of some measurable quality characteristic. There is little basic difference in the attitude of management toward scrap losses and waste losses, or toward final product rejects and final product purity. However, there are some characteristics of chemical processing which require special attention when control procedures are to be established. Two of the most important of these are:

(1) In chemical processing we are usually dealing with a more or less continuous flow of a product material, rather than with specific manufactured items. At best we may be dealing with a batch process, in which a given quantity of material is processed as a distinct unit, roughly corresponding to a lot of manufactured items; at worst(from the point of view of control) we may actually have a continuous production flow with the material divided into discrete units only as bottles, carboys, drums, tankcars, etc. of raw materials received and final product produced. Thus in place of variation of a quality characteristic from item to item we are faced with a continuous process variation measurable only in terms of the average quality of some arbitrary unit of quantity.

(2) Even supposing that we do have some natural unit on which to base our measurement of product variation, it is difficult to establish what this variation should be—i.e., to what it should be compared for control purposes. This is due to the fact that in determining the average quality level of a batch of a chemical we have to face not only the sampling variation due to lack of homogeneity within the batch, which is somewhat analogous to the variation within a lot of manufactured items, but also the variation in the analytical determination of the quality of the sample.

It is the relative magnitude of this measurement error which constitutes one of the major differences between chemical process control and the control of a mechanical process. In the latter case it is generally possible to measure the quality characteristics of an individual item, such as weight, length, inside diameter, clearance, breaking strength, hardness, etc., with sufficient accuracy so that the measurement error can be neglected, and the variation in the results assumed to be due completely to process variation. However, in chemical production the best analytical determinations of the quality of a batch of raw material of product, or a sample from this batch, frequently vary as much as or more than the average quality of the batches themselves.

The data shown in Table I are typical of these considerations. These are the results of a special study of the metal content of two types of metallic oxide, produced by essentially the same process from two types of raw material. The lots of each type represent consecutive production, and the sampling and analytical techniques used were identical. Two distinct samples were taken from each lot by a "thief" technique, and after some additional preparation submitted to the laboratory, where two different chemists did independent duplicate determinations of the metal content in percent by weight. The pairs of chemists assigned were not necessarily the same, nor necessarily distinct, depending on chance assignment in the laboratory. Estimates of the variance components obtained from these data are given in Table II.

*Paper presented on the program of the Sixth Annual Convention, ASQC, Syracuse, N.Y., May 1952.

TABLE I—Results of a Special Study on Consecutive Lots of Metallic Oxide

Lot	Sample A				Sample B			
	Chemist 1		Chemist 2		Chemist 1		Chemist 2	
	1	2	3	4	1	2	3	4
Type 1								
1	84.1	84.0	84.3	84.3	84.1	84.0	84.1	84.1
2	84.1	84.0	84.0	83.9	84.2	84.2	83.7	84.6
3	83.5	83.5	83.4	83.6	83.4	83.3	84.0	83.5
4	84.2	84.2	84.2	84.3	84.1	83.7	84.1	84.6
5	83.7	83.8	83.3	83.3	83.2	83.1	83.1	83.2
6	84.0	84.2	83.8	84.2	84.1	84.3	84.2	84.1
7	84.0	83.8	83.8	84.0	83.6	83.8	83.9	83.8
8	83.8	83.9	84.0	83.9	84.0	84.0	84.2	84.0
9	84.2	84.5	84.3	84.1	83.8	83.7	83.8	83.8
10	83.6	84.0	84.0	83.7	83.9	84.1	84.2	83.7
11	84.6	84.6	84.0	83.4	84.4	84.5	83.9	84.1
12	83.3	82.9	83.2	83.9	82.9	83.7	83.3	83.4
13	84.5	84.5	84.0	84.2	83.7	84.0	84.0	83.9
14	83.8	83.8	83.5	83.6	84.3	84.1	83.8	83.8
15	84.2	84.1	83.8	83.8	83.8	83.8	83.9	83.9
16	84.2	83.4	83.7	84.1	84.4	84.5	84.0	84.0
17	83.3	83.4	83.9	84.0	82.2	82.3	82.4	82.7
18	83.6	83.7	83.6	83.5	84.1	84.0	84.4	84.2
Type 2								
1	83.4	83.4	83.6	83.5	83.7	83.5	83.1	83.4
2	84.2	84.1	84.3	84.2	84.2	84.2	84.3	84.2
3	83.5	83.5	84.2	84.5	83.4	83.7	83.9	84.0
4	83.4	83.3	83.5	83.1	84.2	84.2	83.3	83.1
5	83.2	82.8	83.1	82.7	83.0	83.0	83.2	82.7
6	80.2	80.7	80.8	80.7	80.3	80.4	80.2	79.0
7	80.9	80.6	80.3	80.6	81.0	81.1	80.7	81.0
8	83.3	83.5	83.5	83.4	83.9	83.7	83.7	83.7
9	82.9	82.6	82.8	82.9	83.1	83.1	82.9	82.7
10	83.8	83.8	83.9	83.8	83.4	83.6	84.0	83.8
11	83.8	83.4	83.6	83.8	83.8	83.6	83.9	84.0
12	83.2	82.5	83.0	83.5	84.3	83.5	83.8	83.8
13	83.4	83.4	83.3	83.3	83.5	83.5	83.2	83.3

TABLE II—Estimated Variance Components

Source of Variation	Type 1	Type 2
Lots	0.0620	1.3673
Samples	0.0683	0.0252
Chemists	0.0201	0.0407
Determinations	0.0423	0.0492

In this case the primary interest was in the variation between lots, as an indication of the adequacy and consistency of the processing, so that all of the last three sources of variation, including sampling, can be considered as measurement error, as opposed to processing error. In controlling a continuous flow, variations from sample to sample are frequently the only indication of product variation, and hence sampling error would be included with process variation. Note that for Type 1 lots the estimated measurement error is actually greater than the variation between lots. However, for Type 2 material the variation between lots is appreciably greater than the variation in measurement, although this is primarily due to the large discrepancies in lots 6 and 7. The overall measurement error is comparable for the two types of material, as might be expected; although the difference in sampling variation approaches significance, no apparent reason for this could be found, and the difference is in the opposite direction from that to be expected from the nature of the material processed.

One of the immediate consequences of the presence of an appreciable measurement error, such as that exemplified above, is that adequate control of the process is possible only if we have adequate control of the measurements. Since most chemical process control measurements are based on chemical analyses of one type or another, this means that the statistical control of a chemical process must inevitably be preceded by the establishment of statistical control over the analytical facilities used, whether in the form of analytical instruments used by production personnel or analytical laboratories whose primary function is the analysis of control samples. Such control can be established by the analysis of standard samples, which enables an evaluation of both the variation in the determination and the presence or absence of an appreciable bias, and/or by repeated determinations of the content of a particular batch. How much control of either or both of these types is possible will be dictated by the economics of the particular situation considered.

The use of standard samples enables the determination of systematic bias; however, in most other respects it is inferior to the use of repeated measurements as a means of controlling measurement errors. It should be pointed out that although it is rarely possible to routinely analyze each lot in the systematic manner used in the above special study, the repeated analyses used for measurement control (generally two, and occasionally three or four), should include as many of the sources of measurement error as is economically feasible.

Consider, for example, the validity of concluding that there had been a real variation in the processing of lot 6, Type 2, based on the first two results as opposed to the validity of the same conclusion based on the second and next to last results.

First let us suppose that we have established satisfactory control of gross measurement errors. There will still remain a random measurement variation which may be of the order of magnitude of the variation in the product. The general effect of the presence of such an error is to lower our power to detect abnormal process variations, i.e., a given change in the process average will have less chance of occasioning a point out of control.

To illustrate this effect, let us consider a process for which the normal batch-to-batch variation is σ_p^2, and the normal measurement variation (including any reduction due to replicate measurements) is σ_m^2. Then the overall variation in an individual result is given by $\sigma^2 = \sigma_p^2 + \sigma_m^2$, and control limits for an individual result would be of the form $\mu \pm k_1 \sigma$, depending on the type of limits used.

We can now easily compute the probability that a shift in the process average of $k_2\sigma_p$ will produce a point out of control. Plots of this probability versus k_2 are shown in Fig. 1 for $k_1 = 2, 3$ and $r = 0, 1, 2$, where $r = \sigma_m/\sigma_p$ is the ratio of the measurement standard deviation to the process standard deviation. $r = 0$ corresponds to the usual situation

where any change in the process average is compared to the process standard deviation.

For example, using 3-σ control limits the probability that a change in process average of three times the process standard deviation will produce a point out of control is about 0.50 for r = 0 (no measurement error), while for r = 1 (measurement variation and process variation the same) this probability is reduced to about 0.19. Note that the greatest decrease in power occurs with respect to process variations which are of the magnitude of $k_1\sigma$; large changes in process average will almost certainly be detected in any event.

There is no hard or fast rule as to when the above situation becomes untenable. If, in spite of the fact that the usual process variation is of the order of magnitude of the measurement error, changes in process average of engineering or chemical significance are quite large, the control available may be perfectly adequate. If changes of the order of, say, three to six times the process standard deviation are of engineering significance, then it may be necessary to reduce the measurement error. This may be done by making repeated measurements on a batch; for example, the estimated variation of the measurements for Type 1 material given in Table II could be made less than the estimated process variance simply by taking two samples and assigning them to different chemists for duplicate determinations of the metal content. However, the use of repeated measurements for this purpose, as opposed to their use to control gross measurement errors, is frequently economically unsound.

A better, although sometimes difficult, solution is to develop sampling and analytical procedures which have a sufficiently small random error. If neither of these is feasible, we must simply resign ourselves to a control which is less sensitive to changes in process average than we would prefer.

A final consideration, which may give us additional insight into the adequacy of a method of measurement for the control of a chemical process, is that we are frequently interested as much, if not more, in the content of a particular batch as in the variation in content from batch to batch, or changes in the process average. If the measurement errors and the process variations are both reasonably random, we can ask at what point an individual measurement on a batch ceases to be a better estimate of the content of the batch than the process average; i.e., at what point do we begin to introduce more error by measuring than by ignoring the processing variation. The answer, of course, is simple: If the measurement variance is less than the process variance, it pays to measure each individual batch, but if the process variance is less than the measurement variance, we are better off to use a well-established process average.

Of course, this conclusion is predicated on a controlled process and controlled measurements, which means that we cannot stop making measurements; this applies only to the decision as to what answer we report on a particular batch. However, it does establish r = 1 as somewhat of a dividing line between adequate and inadequate methods of

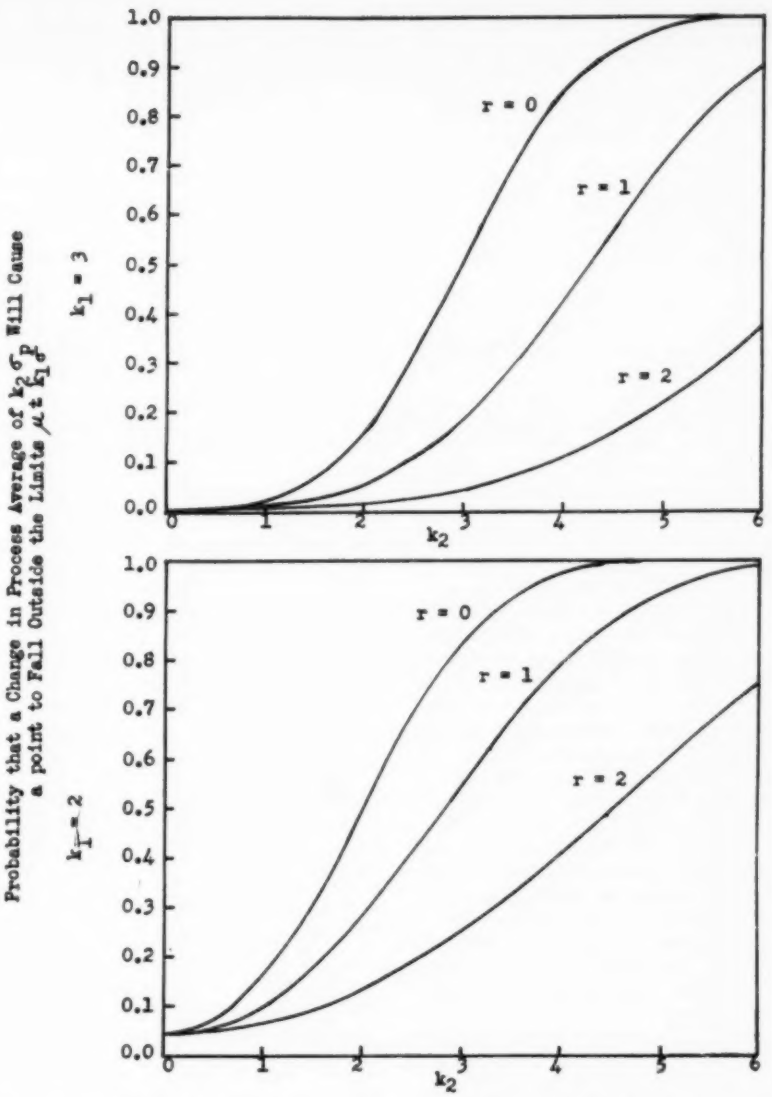
Probability that a Change in Process Average of $k_2\sigma_p$ Will Cause a point to Fall Outside the Limits $\mu \pm k_1\sigma$
$k_1 = 3$
$k_1 = 2$
r = 0
r = 1
r = 2
k_2

Figure 1—Effect of Measurement Error on the Power of the Control Limits

σ_m, σ_p, and $\sigma = \sqrt{\sigma_p^2 + \sigma_m^2}$ are the standard deviations of measurement errors, product variability, and observed results, respectively. $r = \sigma_m/\sigma_p$.

measurement in the absence of other considerations. Actually, on the basis of the data in Table I, and some further indications of the stability of the process for Type 1 material, it was decided to report the process average for each batch of material of this type, and to make analytical determinations only on a composite of five samples from individual batches for control purposes. This procedure was used successfully for some time.

The presence of measurement error to a greater or less extent is characteristic of all chemical processing problems. The above discussion has indicated some of the ways in which we must modify our thinking with respect to the control of the chemical process and some of the considerations which are important in attempting such control. While this is by no means all inclusive of the problems which arise because of the presence of measurement error, it is hoped that those who have to deal with the control of a chemical process can obtain some ideas which will be helpful in their particular problems.

Some Uses of Statistics In the Planning of Experiments

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INTRODUCTION

In order to determine whether the aims of an experimental program are being met, every object of research or development is subjected to tests. The speed and certainty with which the aims are attained depend in large measure on the reliability of the test results and the correctness of decisions based on them.

It is the principal function of statistics in experimental work to plan in advance and to guide the accumulation, analysis and interpretation of test results to improve their reliability and their usefulness to the authority responsible for decision and action.

To illustrate how this function is carried out, it will help to consider what may be called "a general experimental procedure" [G, E, P] shown below

A—Obtain a clear statement of the problem

B—Collect available background information

C—Design the test program

D—Plan and carry out the experimental work

E—Analyze the data

F—Interpret the results

G—Prepare the report

This plan may seem as simple as ABC but it has sometimes happened that the first three steps have been neglected in some measure, and consequently the last steps have become a waste of time and effort. The kind of thinking involved in the statistical approach helps bring the importance of the early steps into proper perspective. The analytical techniques adapted to industrial uses during the past decade serve to improve the reliability of interpretations and to clarify the reporting of results.

As each step is described in detail, it may be possible to impart an appreciation of the uses to which statistics may be put in the planning of experiments.

STATING THE PROBLEM

Although the first stage of research consists of identifying and exploring new problem areas, a project does not firm up, usually, until a specific problem is outlined within limitations of current knowledge and techniques. A sound scientific approach to the experimental program requires that the exact scope of the problem be defined. This insistence on statement of the problem in advance has two purposes:

1. It focuses attention within a small area from which convincing evidence may be secured
2. It meets the requirements of a valid conclusion that the problem be stated without reference to the result

COLLECTING BACKGROUND INFORMATION

This step involves collection of all existing information relating to the problem from the best available sources. Tabulation of pertinent data from earlier work when available has two advantages:

1. It avoids the necessity for repeating work already done, especially repeating mistakes
2. It increases the certainty with which the new experiment may be planned and may reduce substantially the work required to disclose new facts.

DESIGNING THE TEST PROGRAM

As conceived under the statistical approach, the design of an investigation proceeds in three major parts:

1. holding of a planning conference of all parties who have an interest in the problem
2. designing of the test in preliminary form
3. reviewing the program with all concerned

To illustrate this procedure, a very simple example involving textile chemicals is used. The problem is how to improve crease resistance of a textile material by varying the method of application of a given chemical.

1—The Planning Conference. At the preliminary conference, a meeting of minds is obtained on what propositions are to be proved. The proposition in this instance is that crease resistance can be improved by simply adjusting some of the conditions under which the chemical is applied to the fabric. Actually, statistical thinking proceeds from the

"null hypothesis" that no improvement will be obtained and this hypothesis must be disproved if a revised treatment is to be acceptable.

Agreement is then reached on the amount of change which will be required to make the product more saleable or to justify increased cost of the improved treatment, or to be otherwise worthwhile.

Alternative outcomes of the program are considered; for example, an inferior result from the change, or an advantageous condition that would cost too much, or a treatment that would have a deleterious effect on the fabric itself.

A choice is made of the factors to be studied. By process of elimination, concentration of the chemical, temperature of application and drying temperature were chosen for the example. The range through which these factors are to be varied is decided upon. Perhaps even the specific levels of concentration and temperature can be determined at this time. In general, it is advisable to investigate the full usable range of the factors and to try enough levels to satisfy what is known about the likely behavior of the factor. For purposes of illustration, consider use of each of the three factors at its standard level and at some other practical level, designated C_1 and C_2 for concentration, T_1 and T_2 for application temperature, and D_1 and D_2 for dryer temperature.

The end measurements to be made are determined. In addition to measurement of angle of recovery in degrees, the problem requires measurement of tear strength which is important because it cannot be sacrificed for improved crease resistance.

Consideration is given to the possible importance of sampling variability, of the precision of test methods, and of possible interrelationships (or interactions) among the factors. All three of these points are important in the example. Background information indicates that the position of the test piece in the swatch affects the test result and that measurement of the angle of recovery is a sizable element in the variability of results. It is likely that temperature of application will have a much more marked effect at higher concentration, resulting in what is known as "interaction" of the factors.

Consideration is given to the limitations of time, cost, materials, manpower, instrumentation and other facilities and of extraneous conditions, such as weather. There are many times when one or more of these considerations call for strict limitation of the number of runs to be made.

Finally, the preliminary conference takes into account the human relations angles of performing the tests. The necessity for gaining cooperation of all the individuals involved is clear.

2—The Preliminary Design. In the preliminary design of the test program, a systematic and inclusive schedule is prepared of the experimental runs to be made. This schedule may differ considerably from patterns used in the past because instead of varying one factor while all others are held constant, all factors are changed from run to run in a regular pattern. Provision is made for step-wise performance or for adaptation of the schedule depending on results.

Plans are made for the elimination of the effect of variables not being studied by controlling them, or by balancing out or randomizing their effects. The number of tests to be made is minimized within limitations of the information required. Available background information may assist materially in reducing the number of tests needed.

The method of statistical analysis which is to be used is chosen. Arrangements are made for orderly accumulation of the data.

The principal requirements of the design are to keep to a minimum the number of experimental runs, to get as precise a comparison as possible of the effect of changing levels of the factors, to uncover any interactions that exist, and, if it is not independently determined, to measure the experimental "error," or the variability introduced by the inability to reproduce exactly any particular result. Various methods of designing the program for improvement of crease resistance will be explained and a table will be used to compare how each meets the main requirements.

The time-honored method of changing one factor at a time is often referred to as the "classical design" and involves, for example, four runs with the combinations of the three factors at the levels indicated in Table I. It will be recalled that subscript 1 represents a standard level and subscript 2, a trial level of the factor.

TABLE I—CLASSICAL DESIGN FOR IMPROVING CREASE RESISTANCE

Run 1	C_1	T_1	D_1
Run 2	C_2	T_1	D_1
Run 3	C_1	T_2	D_1
Run 4	C_1	T_1	D_2

It is customary to make the first run at the standard level of each of the factors as a basis of comparison. In subsequent runs each of the factors in turn is varied to its trial level while the other two factors are kept at their standard levels. As a result, comparisons between C_1 and C_2, between T_1 and T_2 and between D_1 and D_2 are made on the basis of one result each. (Note that in much textile testing or in ballistic tests, for example, the one result may represent an average of several tests on aliquot samples, or rounds, made during the same run.) Furthermore, unless independent information is available or each run is repeated, no information is given on experimental error. Lacking a measurement of error, it is impossible to determine whether an observed difference is large enough to be significant. Also, no information is given on the interactions of the factors because they have been varied one at a time.

The simplest form of statistical design, perhaps, is the "Latin Square." This is a technique for minimizing the number of runs and therefore has some shortcomings. A Latin Square arrangement for the sample program is given in Table II.

TABLE II—LATIN SQUARE DESIGN FOR IMPROVING CREASE RESISTANCE

	C_1	C_2
T_1	D_1	D_2
T_2	D_2	D_1

Run 1	C_1	T_1	D_1
Run 2	C_1	T_2	D_2
Run 3	C_2	T_1	D_2
Run 4	C_2	T_2	D_1

Involving the same number of runs as the classical design, it has one outstanding advantage in that comparisons between standard and trial levels of each of the factors

may be made on the basis of averages of two results each. The averages of the two columns are used for comparing C_1 and C_2, of the two rows for T_1 and T_2, and of the two diagonals for D_1 and D_2.

Although larger Latin squares will provide a measure of the experimental error, the design shown does not. No Latin square uncovers interactions and in this respect Latin squares are no better than classical designs. Small Latin squares are particularly valuable if an independent measurement of the experimental error is available. They may be used very effectively to screen out the most important factors among a large number under investigation. These important factors may then be grouped in a kind of statistical design that can separate effects of interactions.

The statistical design that maximizes the amount of information from a given number of runs is called a "factorial design." It involves simply making a series of runs with each level of every factor in all possible combinations. For large experiments, this may involve an unmanageable number of runs, so that a variety of useful techniques for reducing the number of runs without sacrificing essential information have been evolved. Handling of some of these designs involves considerable depth of understanding of the underlying statistics and no more can be done here than mention their tremendous effectiveness.[4,5,6]

The full factorial design for the crease resistance example is given in Table III.

It is possible under this plan to make comparisons between averages of four tests each; for example, the average of all four runs under C_1 are compared to all four under C_2. The method of statistical analysis used, called "analysis of variance," results in ability to separate out effects of experimental error and of interactions among the factors.

It may be noted that the Latin square is in effect one half of the factorial design. The effect of cutting the experiment in half, in this instance, was to lose all information on experimental error and on interactions and reduce the precision of comparison. For larger factorial designs, partial performance does not have so stringent an effect. It is also of interest to note that if the classical experiment is repeated, the same number of runs is required as in the factorial case. However, because of the inherent faults in the classical approach, accuracy of comparison is much reduced and interaction effects are still unobtainable.

It should be noted that the examples are minimum designs, used for illustrative purposes, which would be inadequate in most practical situations.

Table IV provides a comparison of these designs in summary form.

TABLE III—FACTORIAL DESIGN FOR IMPROVING CREASE RESISTANCE

		C_1		C_2	
		T_1	T_2	T_1	T_2
D_1	Run 1	2	3	4	
D_2	5	6	7	8	

Run 1	C_1	T_1	D_1
Run 2	C_1	T_2	D_1
Run 3	C_2	T_1	D_1
Run 4	C_2	T_2	D_1
Run 5	C_1	T_1	D_2
Run 6	C_1	T_2	D_2
Run 7	C_2	T_1	D_2
Run 8	C_2	T_2	D_2

3—Review of the design. All parties concerned are given an opportunity to make final comments on the program. The program is spelled out in unmistakable terms for the benefit of those carrying out the experimental work.

ADVANTAGES OF STATISTICAL DESIGNS

This kind of planning has a number of advantages which the older kinds of designs did not have:

1. Close teamwork is required between the statisticians and the research or development scientists with consequent advantages in the analysis and interpretation stages of the program
2. Emphasis is placed on anticipating alternatives and on systematic pre-planning, yet permitting step-wise performance and producing only data useful for analysis in later combinations
3. Attention is focused on interrelationships and on identifying and measuring sources of variability in results
4. The required number of tests is determined reliably and often may be reduced
5. Comparison of effects of changes is more precise because of grouping of results
6. The correctness of conclusions is known with definite mathematical preciseness

PLANNING AND CARRYING OUT THE TESTS

This phase of the work is not directly within the scope of the statistician. However, an orderly approach is desirable, as follows:

1. Developing methods, materials or equipment and applying the methods or techniques
2. Applying theory and possibly modifying procedures in mid-course
3. Attending to and checking details
4. Taking precautions in collection of data and for recording progress of the program

ANALYZING THE DATA

This phase calls for reducing the recorded data, if necessary, to numerical form capable of being analyzed. It requires exercise of care in applying the proper mathematical technique of analysis. Careful training must be given to individuals engaged in this work.

TABLE IV—COMPARISON OF CLASSICAL WITH STATISTICAL DESIGNS
(3 factors, 2 levels each)

Type of Design	Runs Required	Tests Averaged for Comparison	Experimental Error Measured	Interaction Measured
Classical	4	1	No	No
Latin Square	4	2	No	No
Factorial	8	4	Yes	Yes
Classical (repeated)	8	2	Yes	No

INTERPRETING THE RESULTS

When the individuals who undertake to interpret test results have a thorough background in the statistical method of thinking several advantages result:

1. Care is taken that consideration be given to all the data observed
2. Conclusions are confined to strict deductions from the evidence at hand
3. All questions suggested by the data are tested by independent experiments
4. Conclusions are arrived at as to the technical meaning of the results as well as their statistical significance
5. Implications of the findings for application and for further work are pointed out
6. Accounting is made of any limitations imposed by the methods used
7. Results are stated in terms of verifiable probabilities

PREPARING THE REPORT

A good report requires that the work be described clearly with a full explanation of the background and pertinence of the problem and the meaning of the results. Taking full advantage of the statistical method provides some extras:

1. Effective tabular and graphic means of reporting are used
2. Sufficient information is supplied to permit the reader to verify the results and draw his own conclusions
3. Data are presented in good form for future use
4. Conclusions are limited to an objective summary of the evidence so that the work recommends itself for prompt consideration and decisive action

CONCLUSIONS

The advantages of statistics in the planning of experiments are many. In addition to economy of time and effort, the reliability of results is improved and the decisions based upon them are of better quality. Some new techniques are introduced but in general emphasis is placed on exercise of good common sense. As a guide to readers who may wish to supplement common sense with

CHECK LIST FOR PLANNING TEST PROGRAMS

A. *Obtain a Clear Statement of the Problem*
   1. Identify the new and important problem area
   2. Outline the specific problem within current limitations
   3. Define exact scope of the test program
   4. Determine relationship of the particular problem to the whole research or development program

B. *Collect Available Background Information*
   1. Investigate all available sources of information
   2. Tabulate data pertinent to planning new program

C. *Design the Test Program*
   1. Hold a conference of all parties concerned
      a. State the propositions to be proved
      b. Agree on magnitude of differences considered worthwhile
      c. Outline the possible alternative outcomes
      d. Choose the factors to be studied
      e. Determine the practical range of these factors and the specific levels at which tests will be made
      f. Choose the end measurements which are to be made
      g. Consider the effect of sampling variability and of precision of test methods
      h. Consider possible inter-relationships (or "interactions") of the factors
      j. Determine limitations of time, cost, materials, manpower, instrumentation and other facilities and of extraneous conditions, such as weather
      k. Consider human relations angles of the program
   2. Design the program in preliminary form
      a. Prepare a systematic and inclusive schedule
      b. Provide for step-wise performance or adaptation of schedule if necessary
      c. Eliminate effect of variables not under study by controlling, ballancing, or randomizing them
      d. Minimize the number of experimental runs
      e. Choose the method of statistical analysis
      f. Arrange for orderly accumulation of data
   3. Review the design with all concerned
      a. Adjust the program in line with comments
      b. Spell out the steps to be followed in unmistakable terms

D. *Plan and Carry Out the Experimental Work*
   1. Develop methods, materials, and equipment
   2. Apply the methods or techniques
   3. Attend to and check details; modify methods if necessary
   4. Record any modifications of program design
   5. Take precautions in collection of data
   6. Record progress of the program

E. *Analyze the Data*
   1. Reduce recorded data, if necessary, to numerical form
   2. Apply proper mathematical statistical techniques

F. *Interpret the Results*
   1. Consider all the observed data
   2. Confine conclusions to strict deductions from the evidence at hand
   3. Test questions suggested by the data by independent experiments
   4. Arrive at conclusions as to the technical meaning of results as well as their statistical significance
   5. Point out implications of the findings for application and for further work
   6. Account for any limitations imposed by the methods used
   7. State results in terms of verifiable probabilities

G. *Prepare the Report*
   1. Describe work clearly giving background, pertinence of the problems and meaning of results
   2. Use tabular and graphic methods of presenting data in good form for future use
   3. Supply sufficient information to permit reader to verify results and draw his own conclusions
   4. Limit conclusions to objective summary of evidence so that the work recommends itself for prompt consideration and decisive action

the best that mathematical statistical science has to offer, a "Check List for Planning Test Programs" is appended to the paper.

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On the Design of Experiments

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This discussion is intended to provide a glimpse of the thinking that goes into the planning of experiments and to explain the use of some simple tools that are helpful in translating these ideas into effective experimental designs. The discussion is conducted in terms of a single example, but the approach is entirely general.

Let us suppose that we wish to compare two types of ammunition which are supposed to perform alike but which differ enough in methods of manufacture or in other ways that it is meaningful to ask if they are, in fact, essentially the same. Let us say that we are concerned only with the accuracy of the ammunition and that we have an acceptable method of measuring accuracy.

PROPOSAL 1

We might take a number n of cartridges of each of the two types (type 1 and type 2), fire them all from the same rifle and measure the accuracy of each cartridge. The cartridges of type 1 furnish n numbers, $X_{11}, X_{12}, \ldots X_{1n}$ and those of type 2 yield $X_{21}, X_{22}, \ldots X_{2n}$. We wish to decide, on the basis of these two sets of numbers, if there is evidence of a real difference between the two types of ammunition.

The decision would be easy if all the X_1's were equal and all the X_2's were equal. Presumably this would never happen and our decision must be reached in the face of variation within each of our two types.

We should perhaps pause for a moment to realize that observations are always interpreted in terms of a model. What sort of model would we construct to reflect a possible difference between the two types of ammunition and also variation within each type?

In order to cope with variation within types, we envisage the accuracies of all the ammunition of one type assembled in the form of a frequency distribution. This distribution is characterized by a mean, a variance and perhaps other features, but if the distribution is normal the mean and the variance specify it completely. We might express the value of any member X of this distribution as

$$X = \bar{X}' + e$$

when $\bar{X}'$ is the mean and e (the "error") is a member of a distribution identical with that of the X's except that its mean is zero.

In terms of such a model, then, each observation may be expressed in the form

$$\begin{aligned} X_{1i} &= \bar{X}'_1 + e_{1i},\ i = 1, 2, \ldots n \\ X_{2i} &= \bar{X}'_2 + e_{2i},\ i = 1, 2, \ldots n \end{aligned} \qquad (1)$$

Our question is: Can we decide whether or not $\bar{X}'_1 = \bar{X}'_2$, even though we do not know the values of any of the e's?

Several considerations enter into the answering of this question. In the first place, we cannot say anything about the e's except in terms of the distribution from which they came. It is therefore of crucial importance that they come from the distribution in such a manner that the pattern of the distribution be not persistently misrepresented. This is the reason for the insistence on random selection of samples.

Secondly, unless we know more about these distributions than we usually do, we must make provision, in the taking of the observations, for learning something of the nature of the distributions we are dealing with. The sampling suggested under Proposal 1 evidently does furnish information of this kind. Indeed, if n were large enough, we could arrange each of the two sets of observations in a frequency distribution which would, if the samples were randomly chosen, reflect the properties of the distributions from which they were taken. Sometimes it is necessary to take large enough samples to do this. Often, however, we have grounds for assuming that our distributions are not seriously different from the normal type. If this can be granted, it is sufficient simply to estimate the mean and the variance. Smaller samples are adequate for these purposes.

The method that will be adopted here for extracting this information from the samples is one that generalizes easily to more complicated experiments. Let us say, for our illustration, that n = 4, so that four cartridges of type 1 and four of type 2 were tested. The method of analysis consists in transforming the eight numbers yielded by the test into eight other numbers by a transformation chosen to put in evidence the quantities that we wish to examine and also to possess certain other desirable properties that are discussed later.

TABLE I—Transformation Table of Proposal 1

	X_{11}	X_{12}	X_{13}	X_{14}	X_{21}	X_{22}	X_{23}	X_{24}	Divisors
Y_1	1	1	1	1	1	1	1	1	$\sqrt{8}$
Y_2	1	1	1	1	−1	−1	−1	−1	$\sqrt{8}$
Y_3	1	1	−1	−1	1	1	−1	−1	$\sqrt{8}$
Y_4	1	1	−1	−1	−1	−1	1	1	$\sqrt{8}$
Y_5	1	−1	1	−1	1	−1	1	−1	$\sqrt{8}$
Y_6	1	−1	1	−1	−1	1	−1	1	$\sqrt{8}$
Y_7	1	−1	−1	1	1	−1	−1	1	$\sqrt{8}$
Y_8	1	−1	−1	1	−1	1	1	−1	$\sqrt{8}$

The transformation that will be used in this example is shown in Table I, which is presented in a form that avoids as much writing as possible and that displays clearly the important features of the transformation. This array is interpreted to mean that each of the Y's is formed by multiplying each coefficient in its row by the X at the top of the column which contains the coefficient, adding these products, and dividing by the divisor listed at the end of its row. For example,

$$Y_4 = (X_{11} + X_{12} - X_{13} - X_{14} - X_{21} - X_{22} + X_{23} + X_{24})/\sqrt{8}$$

Several facts about this transformation may be remarked at once.

1. The eight X's are converted into eight Y's, so that no property contained in the values of the X's is lost when the X's are replaced by the Y's.
2. When the expressions for the X's that we assumed in our model, Eq. (1), are substituted in the transformation we find:

$$Y_1 = \frac{4}{\sqrt{8}}(\overline{X}'_1 + \overline{X}'_2) + \text{combinations of e's}$$

$$Y_2 = \frac{4}{\sqrt{8}}(\overline{X}'_1 - \overline{X}'_2) + \text{combinations of e's}$$

$$Y_3, Y_4, \ldots Y_8 = \text{combinations of e's}$$

We may agree that Y_1 exhibits values in which we are not interested. Y_2, however, contains the difference between the means, whose evaluation is the chief object of the test. The rest of the Y's express contributions of error only. Thus it is seen that the transformation has accomplished, in some measure, a separation of the two sorts of variation that we envisaged in our model.

If we allow another assumption at this stage, we can go farther.

Assumption: The two distributions are normal and have equal variances.

The assumption that the variances are equal could be subjected to a test and so also could the question of normality if the samples were large enough. We shall not delay over these tests here, but shall proceed on the supposition that the conditions of normality and equality of variances are not seriously violated. It is then a simple exercise in probability theory to prove 3. The proof is not given here.

3. The Y's are distributed in independent, normal distributions, with the same variance as that of the X distributions.

One more result of probability theory will be stated without proof.

Let $V_1, V_2, \ldots V_p, W_1, W_2, \ldots W_q$, (p and q any positive integers) be independent, normally distributed variables with zero means and equal variances. Then,

$$F = \frac{(V_1^2 + V_2^2 + \ldots + V_p^2)/p}{(W_1^2 + W_2^2 + \ldots + W_q^2)/q}$$

has a known distribution (called the analysis of variance distribution or the F distribution). The probability that F should lie in any given range can therefore be calculated and tables are available to assist in this calculation.

Let us return now to the example. We know that, under our assumptions, the values of $Y_3, Y_4, \ldots Y_8$ may be regarded as observations on independent, normally distributed variables with zero means and equal variances and that, if $\overline{X}'_1 = \overline{X}'_2$, Y_2 satisfies the same conditions. Therefore, if $\overline{X}'_1 = \overline{X}'_2$, the ratio

$$\frac{Y_2^2/1}{(Y_3^2 + Y_4^2 + \ldots + Y_8^2)/6}$$

may be viewed as an observation drawn from the F distribution. On the other hand, if $\overline{X}'_1$ differs from $\overline{X}'_2$, this ratio will run to bigger values than would be predicted from the F distribution. This furnishes the basis for a test of the hypothesis $\overline{X}'_1 = \overline{X}'_2$. If the value of the ratio, calculated from our samples, attains a value so large that it would be reached only rarely by an F ratio, we would attribute its large value to a non-zero value of $\overline{X}'_1 - \overline{X}'_2$.

The transformation that converted the X's into the Y's is evidently of crucial importance in this development. The fact, stated above, that the set of independent, normally distributed X's with equal variances transformed into a set of independent, normally distributed Y's having the same variance as the X's, depends on a property of the transformation called orthogonality. This property is ensured by choosing the coefficients of the transformation to satisfy two conditions.

Suppose that one of the Y's, say Y_i, is given by

$$Y_i = a_1X_{11} + a_2X_{12} + \ldots + a_8X_{24}$$

and that another Y, say Y_j, is given by

$$Y_j = b_1X_{11} + b_2X_{12} + \ldots + b_8X_{24}$$

Then, to meet the requirements of orthogonality,

$$a_1b_1 + a_2b_2 + \ldots + a_8b_8 = 0 \qquad (2)$$

and this condition must hold for every pair of Y's in the transformation. Also

$$a_1^2 + a_2^2 + \ldots + a_8^2 = 1 \qquad (3)$$

which condition must also be met by every Y in the transformation.

Evidently it is always possible to write an orthogonal transformation of any number of X's into the same number of Y's. Indeed, there are infinitely many such transformations. Our concern is whether one can be found that will segregate the systematic variations that are present in the data into independent components. This is not always possible, and it is one of the aims in planning the experiment to make it possible.

In an experiment conducted according to Proposal I, the one possible systematic variation envisaged in the model is the difference between the two means, $\bar{X}'_1 - \bar{X}'_2$. We have seen that any contribution from this source is neatly parcelled into Y_2 and appears nowhere else. Therefore the remaining Y's (except Y_1) are left free to display random variation only. The part of the transformation specifying $Y_3, Y_4, \ldots Y_8$ could be given in many different ways, but they would all be equivalent, for the uses we made of these components. To see this, one more simple consequence of orthogonality is needed: The sum of the squares of the Y's is equal to the sum of squares of the X's, namely

$$Y_1^2 + Y_2^2 + \ldots + Y_8^2 = X_{11}^2 + X_{12}^2 + \ldots + X_{24}^2$$

This is easily verified by direct calculation.

Referring now to the transformation of Table I, we see that

$$Y_1^2 = \frac{(\Sigma X)^2}{8} = 8\bar{X}^2$$

$$Y_2^2 = \frac{(\Sigma X_1 - \Sigma X_2)^2}{8} = 2(\bar{X}_1 - \bar{X}_2)^2$$

Therefore,

$$\begin{aligned} Y_3^2 + Y_4^2 + \ldots + Y_8^2 &= \Sigma X^2 - 8\bar{X}_2 - 2(\bar{X}_1 - \bar{X}_2)^2 \\ &= \Sigma(X_1 - \bar{X}_1)^2 + \Sigma(X_2 - \bar{X}_2)^2 \end{aligned}$$

It is clear, from this relation, that the sum $Y_3^2 + Y_4^2 + \ldots + Y_8^2$ is determined completely by the values of of Y_1 and Y_2, provided the orthogonality conditions are met and that the values of $Y_3, Y_4, \ldots Y_8$ need not, for our present purposes, be specified. Indeed, we see that it is not necessary to refer explicitly to the Y's at all to compute the test-ratio, because it is simply

$$\frac{2(\bar{X}_1 - \bar{X}_2)^2}{\left[\Sigma(X_1 - \bar{X}_1)^2 + \Sigma(X_2 - \bar{X}_2)^2\right]/6},$$

which is recognized as the square of the t ratio usually used to test the difference between two sample averages.

It is customary and convenient to summarize the results of the calculations in an "analysis of variance table" like Table II. In ordinary use, of course, numbers are entered instead of formulas. The entries in the "degrees of freedom" column are simply the numbers of Y's squared and added together to form the "sum of squares."

The test ratio is easily calculated from the numbers in the analysis of variance table and it may, if desired, be entered in the table. If the test ratio is significantly large, we can exhibit the difference $\bar{X}_1 - \bar{X}_2$ with some confidence that it reflects something more than error; if the ratio is not significantly large, there is a reasonable chance that error alone could cause so large a difference. This does not prove, of course, that there is no difference. We may have failed to detect a real difference because our error was large. With a view to cutting down the magnitude of the error, we might argue along the lines of Proposal 2.

TABLE II—Analysis of Variance for Proposal 1

Source	Deg. of Freedom	Sum of Squares
Between Samples	1	Y_2^2
Within samples (error)	6	$Y_3^2+Y_4^2+Y_5^2+Y_6^2+Y_7^2+Y_8^2$

PROPOSAL 2

Let us suppose that the powder that goes into these cartridges is produced in batches and that it is not unreasonable to fear that the accuracies of the cartridges are affected by batch-to-batch differences in the powder. This possibility was ignored in the sampling conducted under Proposal 1 and batch-to-batch differences may have added their systematic contributions to the terms that we attributed to error. This could be avoided, of course, by making sure that all the test cartridges were made with powder from the same batch, but this arrangement would yield a comparison of types of restricted value, since there would be no assurance that similar results would be found with other batches. It is obviously preferable to spread the comparison of types over several batches in a controlled fashion, so that differences between batches are not allowed to masquerade as error.

For our example, let us bring only two batches into the test and select randomly two cartridges of each type from each batch. The test results could be presented in a two-way table.

	Batch 1		*Batch 2*	
Type 1	X_{11}	X_{12}	X_{13}	X_{14}
Type 2	X_{21}	X_{22}	X_{23}	X_{24}

The model we must use to interpret these observations is necessarily more elaborate than that used under Proposal 1, because we must provide for a possible difference between batches and also because we must be prepared for the possibility that the difference between the two types of cartridge may not be the same in batch 2 as it is in batch 1.

If we employ the transformation of Table I on these observations, inspection shows that

- Y_2 expresses the overall difference between types, plus error;
- Y_3 expresses the overall difference between batches, plus error;
- Y_4 expresses the difference, between one batch and the other, of the difference between types;
- Y_5, Y_6, Y_7, Y_8 express error only, as reflected by the differences between pairs of the same type from the same batch.

The analysis of variance table now takes the form of Table III.

TABLE III—Analysis of Variance for Proposal 2

Source	Deg. of Freedom	Sum of Squares
types (t)	1	Y_2^2
batches (b)	1	Y_3^2
(t × b) interaction	1	Y_4^2
within pairs (error)	4	$Y_5^2+Y_6^2+Y_7^2+Y_8^2$

TABLE IV—Transformation Table for Proposals 3, 4 and 5

		Test 1				Test 2				Test 3				Test 4			
		(1111)	(1221)	(2121)	(2211)	(1121)	(1211)	(2111)	(2221)	(1112)	(1222)	(2122)	(2212)	(1122)	(1212)	(2112)	(2222)
types (t)	Y_2	1	1	−1	−1	1	1	−1	−1	1	1	−1	−1	1	1	−1	−1
batches (b)	Y_3	1	−1	1	−1	1	−1	1	−1	1	−1	1	−1	1	−1	1	−1
(t × b)	Y_4	1	−1	−1	1	1	−1	−1	1	1	−1	−1	1	1	−1	−1	1
rifles (r)	Y_5	1	−1	−1	1	−1	1	1	−1	1	−1	−1	1	−1	1	1	−1
(t × r)	Y_6	1	−1	1	−1	−1	1	−1	1	1	−1	1	−1	−1	1	−1	1
(b × r)	Y_7	1	1	−1	−1	−1	−1	1	1	1	1	−1	−1	−1	−1	1	1
(t × b × r)	Y_8	1	1	1	1	−1	−1	−1	−1	1	1	1	1	−1	−1	−1	−1
replications (R)	Y_9	1	1	1	1	1	1	1	1	−1	−1	−1	−1	−1	−1	−1	−1
(R × t)	Y_{10}	1	1	−1	−1	1	1	−1	−1	−1	−1	1	1	−1	−1	1	1
(R × b)	Y_{11}	1	−1	1	−1	1	−1	1	−1	−1	1	−1	1	−1	1	−1	1
(R × t × b)	Y_{12}	1	−1	−1	1	1	−1	−1	1	−1	1	1	−1	−1	1	1	−1
(R × r)	Y_{13}	1	−1	−1	1	−1	1	1	−1	−1	1	1	−1	1	−1	−1	1
(R × t × r)	Y_{14}	1	−1	1	−1	−1	1	−1	1	−1	1	−1	1	1	−1	1	−1
(R × b × r)	Y_{15}	1	1	−1	−1	−1	−1	1	1	−1	−1	1	1	1	1	−1	−1
(R × t × b × r)	Y_{16}	1	1	1	1	−1	−1	−1	−1	−1	−1	−1	−1	1	1	1	1

Simple rules for calculating the sums of squares directly from the observations can be developed from the transformation. The details will not be given here.

Test ratios can be set up as before. Naturally one would first set up the ratio

$$\frac{Y_4^2}{(Y_5^2 + Y_6^2 + Y_7^2 + Y_8^2)/4}$$

to test the interaction of types and batches, because if the difference between types varies from batch to batch, no clear-cut meaning can be attached to "difference between types" as displayed by Y_2 and there is no occasion to test Y_2. On the other hand, if Y_4 is not significantly large, one would conclude that the difference between types is reasonably constant from one batch to another and it would be meaningful to test Y_2.

PROPOSAL 3

The comparisons made under Proposals 1 and 2 were carried out using one rifle, but it is not likely that we would be satisfied to assume that the difference between types would be the same in all rifles and we would prefer to spread our test over a number of rifles. Let us say, to keep our example small, that two rifles are to be brought into the test. One of each pair of cartridges of the same type and made from the same batch of powder could be assigned to one rifle, the other of the pair to the other rifle. The results of such a test would naturally be entered in a three-way table, as follows:

	Batch 1		*Batch 2*	
	Rifle 1	*Rifle 2*	*Rifle 1*	*Rifle 2*
Type 1	X_{11}	X_{12}	X_{13}	X_{14}
Type 2	X_{21}	X_{22}	X_{23}	X_{24}

When the transformation of Table I is applied to these observations, we see that, in addition to error,

Y_2 expresses the overall difference between types

Y_3 expresses the overall difference between batches

Y_4 expresses the types × batches interaction

Y_5 expresses the overall difference between rifles

Y_6 expresses the types × rifles interaction

Y_7 expresses the batches × rifles interaction

Y_8 expresses the types × batches × rifles interaction

None of the Y's expresses only the contribution of error; consequently this arrangement makes no provision for estimating error. In some circumstances this may not be a serious defect, but usually it is. In any event, let us take the position that an estimate of error is essential and enlarge the experiment to provide for it. We might think of selecting another set of eight cartridges like the first set of eight, to provide duplicates which would yield an estimate of error in the same manner as they did under Proposal 2. However, let us, for illustrative purposes, take the view that it is not possible to test more than eight cartridges at one time under uniform conditions. We shall therefore run two separate tests, each under uniform conditions but with the possibility that conditions may change somewhat between one test and the other. Estimation of error through differences between duplicates is now impossible. However, the fact that the level of accuracy may be different in the two tests does not stand in the way of assessing error. We are, in these tests, concerned only with comparisons of accuracies, that is with differences, and the error that affects these comparisons is displayed in the variation of the differences from test to test. This is precisely the variation that is gathered together in the "interaction with tests" components, which will therefore be defined as the "error" components. The two tests will be called "replications," since each of them includes a complete set of comparisons.

A transformation of the 16 numbers that would result from such an experiment is shown in Table IV. The headings (i j k l) stands for the accuracy obtained with type i, batch j, and rifle k in replication l. The headings Test 1 . . . . Test 4 and the dotted vertical lines refer to Proposal 4 and should be ignored at this stage. The solid line separates the two replications. The component Y_1 has not been entered in the table and the divisors have been omitted.

TABLE V—Analysis of Variance for Proposal 3

Source	Deg. of Freedom	Sum of Squares
(t)	1	Y_2^2
(b)	1	Y_3^2
(t × b)	1	Y_4^2
(r)	1	Y_5^2
(t × r)	1	Y_6^2
(b × r)	1	Y_7^2
(t × b × r)	1	Y_8^2
(R)	1	Y_9^2
interactions with R (error)	7	$Y_{10}^2+Y_{11}^2+Y_{12}^2+Y_{13}^2+Y_{14}^2+Y_{15}^2+Y_{16}^2$

The analysis of variance table is given in Table V.

The pattern of this experiment is commonly called the randomized block. "Block" here means simply a set of uniform conditions within which all the comparisons of our experiment can be tested. "Randomized" implies that all the observations within a block should receive error contributions drawn randomly from the same error distribution. We have already insisted on randomness in the selection of cartridges for the test. Perhaps we should also insist that, within each block, the cartridge-rifle combinations should be tested in random order. We should certainly insist on this if we feared that there might be some small systematic drift in conditions within the block, but even if none exists, it costs nothing to randomize and nothing can be lost by doing so. The practice should therefore always be followed. This is not to say that we should try to "randomize out" large systematic sources of variation that are known to exist. All that is implied is that randomization should take over where control leaves off.

It may be helpful at this stage to draw attention to some features of the transformations we have been using.

1. Each "main effect" component is formed by summing over all factors except the one whose levels are to be contrasted. It follows from the balance that exists in the arrangement of the experiment that the coefficients of this component sum to zero within each level of each of the factors which do not contribute to this main effect. For example, the coefficients in Y_2, the "between types" component, sum to zero within each batch and within each rifle. This property is most important. If the coefficients of Y_2 did not sum to zero within each batch, for example, Y_2 would include batch differences as well as differences between types. This brings out also the importance of the balance that has been arranged in the experiment. If the balance were disturbed in any way, it would not be possible to find an orthogonal transformation that would separate the various kinds of variation into separate, independent components.

The summing to zero of sets of coefficients provides a useful test for finding out which sources of variation contribute to a given component and which ones do not.

2. The coefficients of the component that specifies the interaction of two main-effect components can be obtained by multiplying corresponding coefficients of the two main effects. This rule simplifies greatly the writing of the transformation.

PROPOSAL 4

Let us suppose now that it is found to be impossible to test as many as eight cartridges under uniform conditions but that uniformity is possible with four cartridges. It is desirable, therefore, to split each replication into two tests, each of four cartridges. There are many ways of making the division of eight into two sets of four and it is important to recognize the consequences of any allocation that may be proposed. For example, suppose that, in each replication, the cartridge-rifle combinations symbolized by (111), (122), (212), (221) are put into one test and the remaining combinations, (112), (121), (211), (222) into the second test. This division is shown by the dotted lines in Table IV. Inspection of the components in the table shows that all but two, Y_8 (t × b × r) and Y_{16} (R × t × b × r) have coefficients that sum to zero within each test. It follows that any differences there may be between tests appear only in these two components, which are thereby sacrificed. If, therefore, we have reasonable grounds for believing that the types × batches × rifles interaction is unimportant, this arrangement provides an acceptable method of taking advantage of such uniformity as can be attained in the conditions of the test.

It is said, of this arrangement, that the types × batches × rifles interaction is confounded with tests. Evidently the sets could be selected so as to confound any one of the components with tests. Indeed, we might confound a different component in each replication.

The analysis of variance table for the confounded arrangement shown in Table IV is given in Table VI.

TABLE VI—Analysis of Variance for Proposal 4

Source	Deg. of Freedom	Sum of Squares
(t)	1	Y_2^2
(b)	1	Y_3^2
(t × b)	1	Y_4^2
(r)	1	Y_5^2
(t × r)	1	Y_6^2
(b × r)	1	Y_7^2
tests	3	$Y_8^2+Y_9^2+Y_{16}^2$
error	6	$Y_{10}^2+Y_{11}^2+Y_{12}^2+Y_{13}^2+Y_{14}^2+Y_{15}^2$

PROPOSAL 5

Let us suppose now that circumstances impose one more condition, that we cannot test (or prefer not to test) more than eight cartridges altogether. Which ones, of the 16 used in Proposals 3 and 4, should be taken?

We could, of course, run one complete replication, as was mentioned under Proposal 3, but in that event there would be no provision for estimating error. Even so, experiments involving large numbers of factors are sometimes run in one replication, with the expectation of using high-order interaction components for estimating error. This practice rests on the principle that the greater the number of factors in an interaction component, the stronger are the general grounds for believing that it contains no systematic conribution from the factors and therefore reflects only error. This is obviously a weaker principle for estimating error than

those used earlier in this discussion, which depend on explicit repetition. One would hesitate to employ it when as few as three factors are involved.

An alternative to running one complete replication is to run twice, one of the two sets into which we divided a replication under proposal 4. We might, for example, run Tests 1 and 3 of Table IV. If we obliterate the portion of Table IV that contains Test 2 and Test 4, we can see what happens to the components when only Tests 1 and 3 are carried out. Y_8 becomes identical with Y_1, Y_7 with Y_2, Y_6 with Y_3, Y_4 with Y_5, Y_{16} with Y_9, Y_{15} with Y_{10}, Y_{14} with Y_{11}, Y_{13} with Y_{12}. Out of all this, we can find seven different meaningful components, which are listed in the analysis of variance table of Table VII. It is to be remembered that the Y's in Table VII refer to Table IV with Tests 2 and 4 removed and the divisors changed accordingly.

We see that the consequence of this arrangement is to entangle completely each main effect with an interaction. It is therefore an intolerable arrangement unless we have strong assurance that certain factors do not interact. When the number of factors is large, we can arrange it so that the main effects are confused only with interaction components of high order that, in all likelihood, contain no systematic effects. Note that this is the same argument advanced earlier to support the use of high-order interaction components to estimate error. Indeed, in many situations, there are few grounds for choosing between using high-order interaction components for the estimation of error and this arrangement, which is called "fractional replication" or "fractional factorial." In the example we have constructed, neither plan would be acceptable.

TABLE VII—Analysis of Variance for Proposal 5

Source	Deg. of Freedom	Sum of Squares
$(t + b \times r)$	1	Y_7^2
$(b + t \times r)$	1	Y_9^2
$(r + t \times b)$	1	Y_4^2
(R)	1	Y_6^2
error	3	$Y_{10}^2 + Y_{11}^2 + Y_{12}^2$

Relationship Between Sample Size and AOQL for Attribute Single-Sampling Plans

IRVING B. ALTMAN

Office of Inspection, Department of Defense

The concept of average outgoing quality limit (AOQL) was first developed in the Bell Telephone Laboratories and is described in detail in Ref. (1).

In order to have available in a concise form the values of AOQL for a large variety of single-sampling plans, AOQL values were computed for acceptance numbers zero and one, which were derived mathematically as shown in the appendix. AOQL values for acceptance numbers greater than one were obtained graphically by use of the binomial tables available in Ref. (3) and Table 15.4 of Ref. (2). It should be noted that the AOQL values were obtained either graphically or mathematically by obtaining the maximum value of pL_p (see p. 110 of Ref. (2)), where it is assumed that the lot size is infinite and all defective items of lots originally rejected on the basis of the sampling plan are removed.

AOQL values for sample sizes up to 300 were plotted on logarithmic graph paper and appear in Fig. 1. Except for small samples at acceptance number zero, the relationship of sample size and AOQL values appears linear on the logarithmic scale. The slopes of the linear relationships for the various acceptance numbers are approximately equal thus giving a series of parallel straight lines which decrease with increase in sample size.

Examination of Fig. 1 reveals the relationship that multiplying the sample size by a constant k reduces the AOQL to 1/k of its original value regardless of the acceptance number. For example doubling ($k = 2$) the sample size will reduce the AOQL by 50 percent ($1/k = \frac{1}{2}$). In other words if the original AOQL were six percent, in order to decrease the value to three percent, it is necessary to double the sample size using the same acceptance number. Reading from Fig. 1, an AOQL of six percent corresponds to a sample size of six (to the nearest integer) for an acceptance number of zero; an AOQL of three percent corresponds to a sample size of 12. Similarly, for an acceptance number of one, an AOQL of six percent requires a sample size of 14; an AOQL of three percent requires a sample size of 28. For the higher acceptance numbers, a similar relationship exists.

Figure 1 provides an easy method for setting up various single-sampling plans catalogued by AOQL. For example, for an AOQL of 1.5 percent defective, the following single-sampling plans may be obtained from the graph: $n = 24$ $c = 0$, $n = 56$ $c = 1$, $n = 91$ $c = 2$, $n = 130$ $c = 3$, $n = 172$ $c = 4$, $n = 210$ $c = 5$, and $n = 253$ $c = 6$. Similarly, single-sampling plans may be set-up for other AOQL values.

Appendix: Derivation of the Equation of AOQL as a Function of Sample Size (n).

1. *Acceptance Number c = 0.*

Let p = fraction defective in lot

(1-p) = fraction non - defective in lot

The probability of obtaining zero defectives in a sample of n is given by the first term of the binomial $[(1-p) + p]^n$; viz.,

$$L_p = (1-p)^n \qquad (1)$$

$$Y = AOQ = pL_p = p(1-p)^n \qquad (2)$$

AOQL is the maximum value of AOQ. Hence

$$\frac{dy}{dp} = -np(1-p)^{n-1} + (1-p)^n = 0$$

$$(1-p)^{n-1}[(1-p) - np] = 0,$$

$$1-p-np = 0$$

$$p(n+1) = 1$$

$$p = \frac{1}{n+1} \quad \text{(value of p for which AOQ is a maximum)}$$

Substituting in Eq. (2) the value of $p = \frac{1}{n+1}$ at which the maximum AOQ occurs,

$$AOQL = \left(\frac{1}{n+1}\right)\left(1 - \frac{1}{n+1}\right)^n$$

$$= \left(\frac{1}{n+1}\right)\left(\frac{n+1-1}{n+1}\right)^n$$

$$= \frac{n^n}{(n+1)^{n+1}}$$

2. Acceptance number c = 1

By algebraic processes similar to the above derivation for c = 0 and by solution of a quadratic equation of p in terms of n the following equation is obtained:

$$AOQL = p_L q_L^n + n p_L^2 q_L^{n-1}$$

where

$$p_L = \frac{n\sqrt{5-4/n} + (n-2)}{2(n^2-1)}$$

$$q_L = 1 - p_L$$

3. Acceptance number c = 2

For acceptance number c = 2, it is necessary to solve a cubic equation of p in terms of n. This solution was prohibitive for the writer and graphic methods were used to obtain the AOQL for the various single-sampling plans.

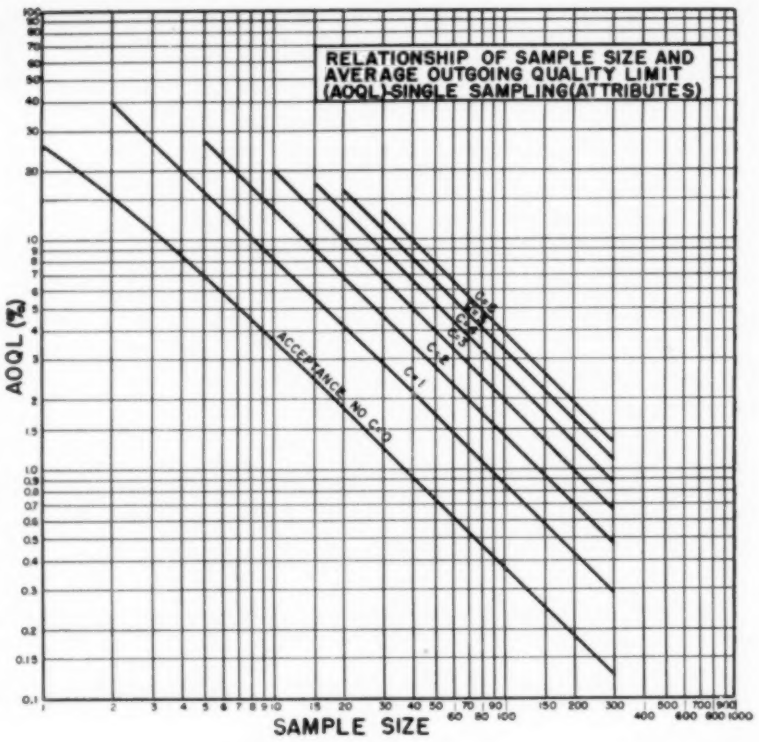

Figure 1

References

1. H. F. Dodge and H. G. Romig, *Sampling Inspection Tables*, John Wiley and Sons, 1944
2. Freeman, Friedman, Mosteller and Wallis, *Sampling Inspection*, McGraw-Hill, 1948
3. "Tables of the Binomial Probability Distribution," National Bureau of Standards, GPO 1949

Comments by Referee

The sample sizes derived in this paper for a series of AOQL values for extremely large lot sizes N, where the ratio $\frac{n}{N}$ is extremely small, are only approximate values. Consequently the relations for AOQL given in Ref. (1), p. 48, equation (18), where $\frac{1}{N}$ is omitted, provide as good values for the sample sizes and AOQL values as those given in this article. The y values in Table A, p. 49, are determined by the use of the Poisson exponential as an approximation to the binomial and are good enough to use in the relation

$$AOQL = p_L = \frac{y}{n}$$

or

$$n = \frac{y}{p_L}.$$

Since

$$y = x \sum_{m=0}^{c} \frac{e^{-x}x^m}{m!} = \frac{e^{-x}x^{c+2}}{c!}$$

per equations (19) and (21), Ref. (1), where $x = p_L n$ and p_L is the value of p where $AOQ = P_A$ is a maximum; i.e., $AOQL = p_L$. From $n = y/p_L$ for $p_L = 0.015$ (the example in the present article), the following values of n are obtained for the same series of c values.

	c								
	0	1	2	3	4	5	6	7	8
y	0.3679	0.8408	1.372	1.946	2.544	3.172	3.810	4.465	5.150
x	1.00	1.62	2.27	2.95	3.64	4.35	5.07	5.80	6.55
p_L	0.041	0.029	0.025	0.023	0.021	0.021	0.020	0.019	0.019
n	24.56	56.05	91.47	129.73	169.60	211.47	254.00	297.67	343.33
n*	25	56	91	130	170	211	254	298	343
n#	24	56	91	130	172	210	253	—	—

*Rounded values to nearest unit per Dodge-Romig relation. N infinite.
#Values listed by Altman in this article.

Practical Aids

ELLIS R. OTT, Editor

Send your "Practical Aid" contribution to:
Dr. Ellis R. Ott
Rutgers University
77 Hamilton Street
New Brunswick, N. J.

Confidence Limits for $\bar{X}'$ When kn Is Less Than 100

ACHESON J. DUNCAN
The Johns Hopkins University

In Professor Burr's recent note on "Confidence Limits on Process Capabilities" (IQC, Sept. 1953, pp. 52-54) the formula for confidence limits for $\bar{X}'$ when σ' is unknown is valid only for large samples. He himself limits kn to at least 100. For smaller values of kn, good results will be given for reasonably normal universes by the formula:

$$\bar{X} \pm u_p \sigma_{\bar{x}} = \bar{X} \pm \frac{u_p \bar{R}}{d_2 \sqrt{kn}} \quad (1)$$

where u_p replaces Professor Burr's t_p factor. Values of u_p for 0.95 confidence limits are given in *Quality Control and Industrial Statistics*, A. J. Duncan, Table E3, and in Table 4 of "The Use of the Range in Place of Standard Deviation in the t-Test," *Biometrika*, E. Lord, Vol. XXXIV (1947), pp. 41-47, (the original source). When, for example, $k = 10$ and $n = 2$, then $u_p = 2.20$ instead of the value of 1.96 from the normal table; similarly, when $k = 5$ and $n = 4$, then $u_p = 2.11$.

For the above formula to be valid, the process must of course be in control. It will be useful mostly when a process has been operating in control at known $\bar{X}'$ and σ', but changes have been made in the process that may change both the level and variability without destroying control. The formula will permit an estimate of the new level of $\bar{X}$ on limited data. Of course, the smaller kn, the wider will be the confidence intervals.

Example. Assume that a process for the manufacture of the base of a fragmentation bomb had been brought under control with respect to the length of the base. The central point on the $\bar{X}$ chart was 0.8343 in. and the central point on the accompanying R chart was 0.0067 in.; this was equivalent to $\sigma' = 0.0032$.

Subsequently, a new machine was introduced. This was set to produce bomb bases whose average length would be the same (it was believed) as that produced by the old machine. It was expected, however, that the variability in length would be reduced by the new machine. After the new machine was in production, samples of four bases were taken at intervals of an hour from the first shift's production. The results are tabulated below and presented in the graph of Fig. 1.

Sample	$\bar{X}$ (n = 4)	R
1	0.8340	0.005
2	0.8293	0.008
3	0.8310	0.004
4	0.8333	0.007
5	0.8288	0 003
6	0.8295	0.004
7	0.8351	0.002
8	0.8344	0.003
Total	6.6554	0 036
Av.	0.8319	0.0045

It was assumed that the process would continue to be in control, but that its average and variability might be different. To study the output characteristics of the new machine as set, 0.95 confidence limits for the new process average $\bar{X}$ and the new standard deviation σ, were obtained as follows:

$$\bar{X} = 0.8319 \pm \frac{2.05(0.0045)}{2.059\sqrt{32}}$$

$$= 0.8319 \pm 0.0008.$$

Thus the limits 0.8327 and 0.8311 do not contain the old $\bar{X}' = 0.8343$.

$$\sigma = \frac{0.0045}{2.059 \pm \frac{1.96(4.698-2.059)}{3\sqrt{8}}}$$

Here again, the limits 0.0031 and 0.0016 do not contain the original $\sigma' = 0.0032$.

These results indicated that both the $\bar{X}$ and σ for the new machine as set were below the old levels since the latter were not contained within the confidence limits.

The specifications on the product were 0.820 and 0.850 in. By taking the lower limit for $\bar{X}$ and the upper limit for σ, it was possible to estimate that, at the outside, the lower process limit would not be below

$$0.8311 - 3(0.0031) = 0.8218$$

which was still within the specifications. Hence, it would be concluded that although the new machine setting was producing at a lower average length, there was still very little risk of any product falling outside the lower specification limit. It would not be necessary therefore to reset the machine.

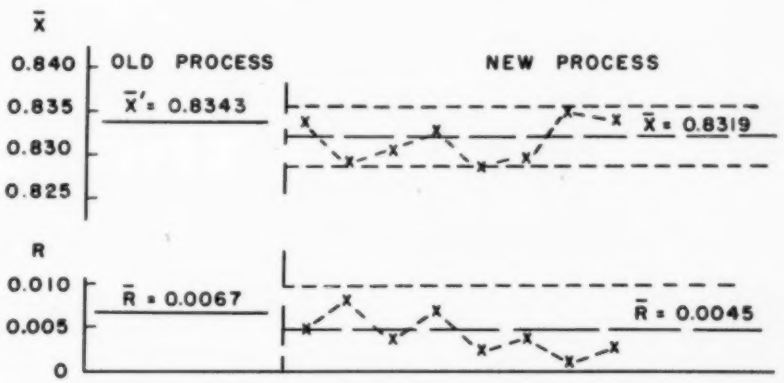

Figure 1

Join the crusade

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AMERICAN SOCIETY FOR QUALITY CONTROL

June 9, 10, 11, 1954 — St. Louis, Mo.

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EIGHTH ANNUAL CONVENTION

SAINT LOUIS, MISSOURI

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November 26, 1953

Fellow Members and Friends of ASQC

Greetings:

In just about six months from the time you read this note in January our 8th Annual Convention will be in full swing. The planning committee is turning all stones in St. Louis to assure you "A Great Convention." May we again suggest, "The Early Bird Gets the Worm" so make your plans and reservations early for St. Louis—June 8-9-10-11.

Now, you wonder why June 8th has been added? Here's your answer. Anheuser-Busch will be your host on Tuesday evening for a pre-Convention Social evening. To those who attended the 4th National Convention, need we say more? Complete details will be made known later. Our Social Evening, scheduled for Wednesday evening, will definitely follow a pattern. Just wait and see! A full ladies program has been added, will you bring them? Enough of the Social life, now for the Students.

Our Technical program is set. There will be 67 Technical and Advanced sessions available from which to choose. You can take your pick. The Program Committee has attempted to present as many fields of Quality Control as the overall program would allow. We feel sure you will like their offerings. Several plant tours will be available every afternoon. Again you take your pick. Some, however, will be limited as to number. First Come—First Served.

Kiel Auditorium will be the scene of our Convention Activities for Technical Sessions, Exhibitors and Luncheons. Our Luncheons will be served on the Main Arena Floor. The overflow, to the Balcony. Good seats too! Our Exhibitors will be in the Exposition Hall. We are set up for the largest Exhibitor display in the history of our Conventions, and we have ample room for expansion. The Convention Banquet and Social Evening will be in the Gold Room of Jefferson Hotel.

It is hoped these highlights will arouse your interest for early Registration, both in the Hotel and for the Convention. Be sure to use the Hotel reservation form. It will assure you firm reservations.

So till the Convention Committee can welcome you in person June 8th, we all wish you "happy planning."

Cordially and sincerely yours,

P. K. Leatherman

Paul K. Leatherman

APPLICATION FOR HOUSING ACCOMMODATIONS

ST. LOUIS, MO.

For your convenience in making hotel reservations for the coming meeting of the American Society for Quality Control on June 9-12, 1954 in St. Louis, hotels and their rates are listed below. Use the form at the bottom of this page, indicating your first, second and third choice. Because of the limited number of single rooms available, you will stand a much better chance of securing accommodations of your choice if your request calls for rooms to be occupied by two or more persons. All reservations must be cleared through the housing bureau. ALL REQUESTS FOR RESERVATIONS MUST GIVE DEFINITE DATE AND HOUR OF ARRIVAL AS WELL AS DEFINITE DATE AND APPROXIMATE HOUR OF DEPARTURE, ALSO NAMES AND ADDRESSES OF ALL PERSONS WHO WILL OCCUPY RESERVATIONS REQUESTED *MUST* BE INCLUDED.

Hotel	For one person	For two persons		2-Room Suites
		Double Bed	Twin Beds	Parlor & Bedroom
BALTIMORE	$4.50-$ 8.50	$6.00-$10.00	$6.50-$11.00	
CLARIDGE	4.00- 8.00	6.50- 8.50	7.50- 9.50	$16.00 & up
DESOTO	4.50- 7.50	6.50- 10.50	8.00- 10.00	16.50-$19.00
JEFFERSON	5.50- 9.50	8.50- 12.00	9.50- 14.00	24.00- 37.50
LENNOX	5.00- 9.00	6.50- 10.00	9.00- 11.00	16.50 & up
MAJESTIC	4.50- 8.50	6.50- 11.00	7.50- 12.00	
MARK TWAIN	4.00- 7.50	5.50- 9.00	8.00- 9.00	12.50 & up
MAYFAIR	5.00- 10.00	6.50- 12.00	8.50- 12.00	14.50 & up
STATLER	5.00- 11.00	7.50- 14.00	9.00- 16.00	28.50- 30.00

In the event that the hotel room rate structure is changed prior to the above convention these rates will be changed accordingly.

ALL RESERVATIONS MUST BE RECEIVED PRIOR TO: MAY 10, 1954

Hotels Convention Reservation Bureau, ASQC

Room 406—911 Locust St.

St. Louis 1, Mo.

Please reserve the following accommodations for the:

American Society for Quality Control in St. Louis, Mo., on June 9-12, 1954

Single Room.....Double Bedded Room.....Twin Bedded Room.....

2 Room Suite.....Other Type of Room.....

Rate: From $.....to $.....

First Choice Hotel.....

Second Choice Hotel.....

Third Choice Hotel.....

Arriving at Hotel (date).....hour.....A. M.....P. M.....

Leaving (date).....hour.....A. M.....P. M.....

THE NAME OF EACH HOTEL GUEST MUST BE LISTED. Therefore, please include the names of *both* persons for *each* double room or twin bedded room requested. Names and addresses of all persons for whon you are requesting reservations and who will occupy the rooms asked for:

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(Individual Requesting Reservations)

Name.....

Address.....

City and State.....

If the hotels of your choice are unable to accept your reservation the Hotels Convention Reservation Bureau will make as good a reservation as possible elsewhere providing that all hotel rooms available have not already been taken.

Guest Editorial

On the Technical Development of the Society

JULIAN HARRISON TOULOUSE

FOREWORD

Nearly every individual finds himself on occasion in need of mentally reviewing what he has done with his life, and what he should be accomplishing in the future. Such soul searching may be brief or long, spasmodic or planned, but no matter how approached, often results in momentous decisions for the future.

So it should be with societies, and it is particularly true in the American Society for Quality Control whose growth has been so rapid, and the interests of individual members so varied, that goals and policies can be quickly out-grown.

When the society consisted of only a few hundred people, when there were relatively few in any one industry or field of work, and when methods were few and being rapidly developed for more general interest, each member had a more common goal, (to learn *something* about quality control) with less of an industry separation. My feeling is that these interests are changing.

The histories of the development of the large technical societies show an eventual separation into fields of interest. The 80,000 members of the American Chemical Society of which I am also a member cannot all have the same interests—hence it has many divisions, as the Division of Organic Chemistry, of Physical Chemistry, of Analytical Chemistry, to name a few. The primary membership is in the Society (one cannot be a member of a division unless already a member of the society), and the secondary membership is in the division. Each division charges its members an additional dues, for otherwise the individual members not interested in a field would be paying the costs for only a few. Divisional expenses are nominal, usually one or two dollars in addition to society dues much larger than ours, but it includes postage, news letters, organizational expense and the like, which benefit only the members of that division.

The American Society for Testing Materials, in two of whose committees I have been active for some time, preserves its groups as committees only. However its membership is largely, though not exclusively, composed of corporations, and its committee action is largely confined to test methods and procedures of "official" character. The committee set-up is more practical here. It does not have committee dues.

A member of most of these societies may belong to as many divisions or committees as he wishes, or for which he is qualified.

Editorial Note

In the July 1951 issue of this Journal there appeared an editorial under the title of "Operation Blueprint." The editorial was aimed at stimulating Society thinking about the constructive formulation of realistic and attainable objectives.

In the November 1951 issue there was published a very significant paper, contributed by Dr. J. M. Juran, under the title "Directions for ASQC." In this paper, Dr. Juran gave some very concrete and explicit suggestions for the future development of ASQC along lines that he felt were necessary for its continuing growth and usefulness.

Since then, much has been going on behind the scenes, and some progress has been made. A large share of the credit for such progress as has been achieved certainly goes to Vice President Julian H. Toulouse. Much remains to challenge the attention of both the officer group and the individual membership.

And, as the old sun dial motto says, "It is later than you think!"

The present "Guest Editorial" by Mr. Toulouse is presented, not as an official document from a society officer, but as the voice of one member of our organization who has, unquestionably, given more thought and effort than any other single person to the matter of how best ASQC can plan to meet the opportunities that have been thrust upon it.

It is an earnest, constructive article deserving your attention. Read it, think about it, respond to it either directly or through your local section officers.

Mason E. Wescott

In the structure of the American Society for Quality Control, the divisional organization is relatively new. Most of the technical activities are handled by committees of limited membership. It is my feeling that from the standpoint of the individual member, what we call divisional activity (or by any other name), will rapidly become increasing important. I personally urge that such activities be encouraged, and that every member of the society think carefully about the subject.

OBJECTIVE

This editorial has as its object the promotion of a discussion leading to increasing divisional activity on the part of our members.

The major reason is that our membership has grown so large that new or recent members find themselves somewhat lost or bewildered. They do not realize the great activity in their field of work. They see few technical papers in their field because the limited space of *Industrial Quality Control* does not permit a steady flow of papers in any one industrial field. Since for every member who attends the convention there are nearly four who cannot, the published convention papers covering fifty to seventy discussions in many fields of application are not seen by almost 80 percent of our members. All too few take advantage of the offer of the printed convention papers. In short, the bulk of the membership does not appreciate the many opportunities which are there for the taking. Since it is largely the long-time members who go to the convention, the newcomers easily become part of that unfortunate "statistic"—member turnover.

The technical committee, as now constituted, is a small organization. Membership is limited to appointments, usually to *active* workers on subcommittees or task forces. Its officers are appointed. Only those whose names appear on the annual committee lists are actually members of the technical committee, and thus membership ranges from 5 to 20 members, and no more. Thus the

committee cannot welcome these new members as observers to learn or listen only.

Much work is done, and technical papers on standards, or other results, in time are published. In spite of much good work by the committee a vast majority of society members in the particular field seldom see the results, or achieve the feeling of "belonging"—they do not even have a "passive" membership in the committee so far as their industry is concerned.

Committees seldom hold open meetings, clinics, or conferences, although there is a trend in that direction. They are doing an excellent job of sponsoring and suggesting subjects and speakers for national convention speeches and papers. In general, however, a committee is an agent of the society's management functions, a fact finding body, and not a conference, or a clinic, or a means of general member contact.

DIVISIONS FOR ASQC

The established structure for divisions in the American Society for Quality Control is different. Membership is open to any member working or interested in that field. Its officers are elected by its members. Conferences can be sponsored, and are encouraged, with programs of speakers of direct interest to members of that division. Published conference papers get distribution among members and are available to others attending the meeting, or by purchase away from the conference. Technical Supplements can be developed as desired (cost limits committee-sponsored supplements) because the division can underwrite the cost through conference fees. In short, the opportunity for worthwhile results is increased, and a member of the society can feel that he "belongs." His passive membership becomes active.

There are presently two divisions operating within the Society. First organized was the Textile Division, which has already planned its fifth annual conference, has issued one Supplement and has completed arrangements for a second. Its membership has passed the 165 mark, and it has aroused the interest of every quality control man in the industry.

The second to be formed was the Chemical Division. It has just completed its first year, and its membership has already passed 200. Its many fields of activity should make it one of the largest of our divisions.

The writer's assignment as Trustee of these divisions, and work with the committees has given him an excellent chance to observe their several differences and approaches to their goals; and while both the divisions and the technical committees are of great importance in their fields, it appears that the greatest enthusiasm and impetus, as well as member opportunity, lies in the divisions.

There are some definite questions to be answered in making a decision as to the divisional growth and activities. To list a few may be inadequate in coverage, but they will define some aspects of the problem.

1. Should divisional dues be charged and if so, how should the collection be made? Precedents for divisional dues, or no divisional dues, can be found.

2. Should the division sponsor conferences separate from the existing regional conferences and national conventions? One aspect is the question: should the national and regional meetings be devoted more to methodology? Another aspect is the question of the ever growing program of papers in all the conventions and conferences.

3. Should the publications of regional conference papers, of national convention papers, and of divisional or committee conferences papers and supplements be limited to those papers meeting the standards of *Indstrial Quality Control*?

These and similar problems have strong proponents and valid reasoning in either direction, and both directions of opinion should be heard in the final planning.

TENTATIVE PROPOSALS

If the division idea grows, long-term planning is needed as well as decision. The two present divisions are logical and well contained. But there are many, many fields of activities, and even the Textile or Chemical Division might feel the urge to separate into sub-fields. Some planned organization must be made, on paper, long in advance of the need, so that we do not reach a position of having a multitude of heterogeneous divisions. Here is my proposal for limiting the number of divisions to seven, or to eight at the most, but with ample room to grow in coverage within the division. They would be as follows:

Textile
Chemical
Metals
Manufacturing and Assembly
Transportation
Electronics and Communication
Business Administration and Operations
Military Affairs

Let us examine these eight fields, making a guess as to the lines of interest, and the sub-groupings. Let us also not lose sight of the fact that this is one man's opinion only, and that serious minded workers in each field should be able to set forth more clearly both the similarities and the differences in the fields of activity and in the organization within the division.

I apologize in advance where I have not understood the present committees, subcommittees, or activities.

In discussing these present and "phantom" divisions, there will be noted several points of differences, as well as likenesses. The structure of each division will vary according to the make-up of the industries so grouped, and their community of interest.

In general I would like to propose that the name "committee" within a division be used for the major groupings within that division. In some it would be the name of an industry—in others the name of a field of work, as Industrial Engineering.

The activities of a committee within a division might be divided into two general fields. One field would include the organizational activities, with the name "subcommittee" used, as the "subcommittee on membership," "on speakers," or the like. These subcommittees would in general be standing subcommittees. The second general field would be concerned with specific problems, and some use of the name "task group" is already made. Task groups would include some of temporary nature.

Making a primary breakdown by industry groups seems logical, but it tends to subordinate methods and applications common to others in the whole division. My proposal for handling this is to unite the subcommittees and task forces within the division, as "joint subcommittee on speakers," or "joint task group on control charts." In other words, while still keeping the industry breakdown where it applies, and allowing every opportunity for the industry to work out its problems,

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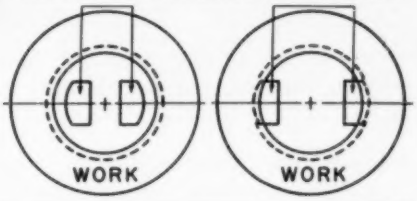

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there should still develop a strong cooperation between committee subgroups having the same field of application.

The Textile Division

The present activities within this division, in addition to general committees on publications, membership, by-laws, etc., are best typified by task groups named according to the problems now under study. They are:

Cotton Raw Stock
Staple Fibre Picker Laps
Staple Fibre Sliver and Roving
Staple Fibre Yarn

Other committees and task groups will no doubt be created, particularly in fields beyond the raw material, preparation of fiber or weaving stages. Garments, garment standards (sizes, etc.) and similar topics might well become added. Government specifications, tolerances and inspection details will be of great importance to this industry because much of it is visual inspection. Already the Automotive Technical Committee has named a field of cointerest in terms of automotive textiles, so that inter-industry liaison has become important.

Even with the operations field so outlined, the kind of fiber presents another possible break-down. Cotton, wool, flax, jute and other natural fibers each suggests a field of specialized activity. The many chemical fibers, or plastics, or fiberous glass add new possible breakdowns, either as individuals, or as classes. They have both related, and unrelated, quality problems and controls.

From the member point of view, each possible field presents an area of similarity, an area of difference, or an area of sequence of operations which should be of importance. Each field has enough similarity along certain phases to command a community of interest to members of the division, and thus to promote broad general discussions as in joint task groups; yet each also presents problems of primary interest to a limited few. There should be a welding of interest, and the development of a strong divisional feeling easily obtained. The fact that this division is sponsoring its fifth annual conference and its second set of conference papers, bespeaks its growing strength.

As presently constituted, and as outlined for the future, there should not be a textile industry member of the society who could not find a direct sphere of interest in this division. Particularly the activities of the division should grasp and hold the interest of each new member, provide him with a stimulation, give him something of immediate application, and retain his interest. He could receive something of value during his first year of membership, to justify his continued membership in the society. The same is true of each of the proposed divisions.

The Chemical Division

The Chemical Division has a number of committees on general subjects (similar to those of other divisions and committees) including: publications, program, membership, nominating, on committees, and on by-laws. It is interested in bulk sampling, and in methods of quality control in the ceramic industry. It is setting up a committee on paper and graphic arts. One important development has been a news-letter. It has also circulated a questionnaire on member interests, and has supported a speaker's program to reach each section of ASQC.

This division presents a different grouping of interests than the Textile Division. Its members represent two fields of chemisty: one in the field of pure chemistry or chemical manufacture, and the other in the fields of applied chemistry.

One grouping of the division might well be in the field of pure and of manufacturing chemistry, where problems in the control of chemical reactions or of analysis is a matter of probability statistics. In this respect the presence of strong organizations in other societies in these fields will have an important influence on the developments within the division.

This division might also be subdivided by industries, of which chemical manufacture is one, but which might also include the rubber, plastic, food, petroleum, ceramic, pharmaceutical and similar examples of applied chemistry.

Even these might be further subdivided: food, for instance, would have many sub-interests in meat, dairy, cereals, grains, and also fruits, vegetables, seafoods, distilled spirits, wines, carbonated beverages, canning, preserving, packaging and

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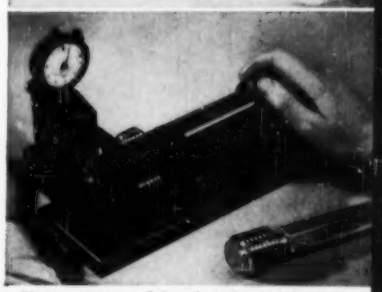

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the like. Paper has many forms as liners, corrugated and fiber-board, writing, printing, processing, and similar formations; not to mention raw materials—c o o k i n g, jordans, milling, fabrication, or other preparation processes.

Part of the thinking which has prompted this discussion has been the question of a separate Paper Division. I once seriously favored such a step until more careful study indicated what a precedent it could become toward *other* divisions of even more limited interest. As it is, paper may become one of the important committees of the Chemical Division. And today, members in the food industry are considering a similar committee formation. No doubt others will follow.

So far we have considered actual divisions. Now let us turn to those divisions which should exist only on paper, *until each grows up to this need.*

Metals

There is already a strong Metals Technical Committee. It may continue as such for a long time. Only the decision of members of the industry in our Society should bring about a change in structure, in this, or any other group. With the formation of this committee a year ago it was decided that any change in structure should be determined on the basis of success as a committee first.

To me there are several logical groupings in this committee or division. Any one of them could be adopted. The ferrous and non-ferrous groupings came to mind, but the ferrous group includes cast iron, wrought iron, steel, and many alloys other than steel. The non-ferrous group could become as varied as there are metals other than iron.

Another grouping might be by stages in the process: smelting, blast-furnace, c o n v e r t e r, open hearth, cupola, ingot, pig, rolling, forge, foundry or the many other designations applicable. Note that all of these define the scope of such a division to the *preparation* of the metal. Each has its area of control workers in the combined field, both as a whole, and in the several groupings indicated.

Manufacturing and Assembly

This is a wholly new "phantom" division. It seems a logical grouping for many manufacturing operations; particularly in the metal working field it should bring together the many-faceted interests in machine-tool operation, g a g i n g, pattern making, job shop, subassembly, final assembly, inspection both of parts and assemblies, standards, tolerances, and a host of interests too many to list or know. Many discussions of this field have been held at our conventions and conferences. A specialized group in this subject seems very much needed to further continued interest, and it awaits only the evidence of a strong enough group to activate it. Two committees now exist in which a great part of the activity is in this field: the Aircraft and the Automotive Committees, much of whose interests are in manufacturing and assembly problems.

Transportation

There are now two technical committees which touch on this field but which have greater interests in manufacturing and assembly. Each has its area of differences, but also its area of similarity. Many companies operate both in the transportation activity fields of the Aircraft Committee and the Automotive Committee. Many others are in one field only, of these two.

But there are other fields of transportation. The railroads are making increased use of the statistical method and should have a forum for discussion. Water transportation is still a vague possibility in my own knowledge, but it should have a place prepared for it, if and when interest is found. Diesel motive power may be a separate field, of interest to railway, truck and sea uses. Eventually a division might come out of the community of interests, and even rivalries in transportation.

It is also possible that the purely transportation problems of this division might be considered part of the Business Administration Division, discussed in a following section.

Electronics and Communication

The present Electronics Committee has two subcommittees as follows, both of which include vendor certification:

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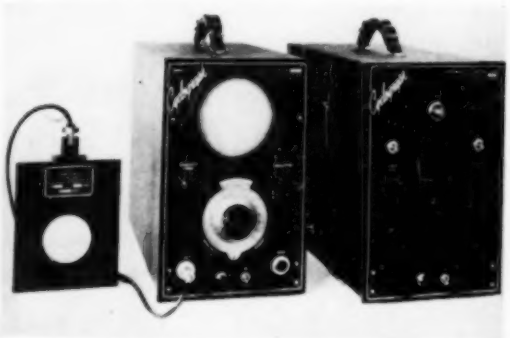

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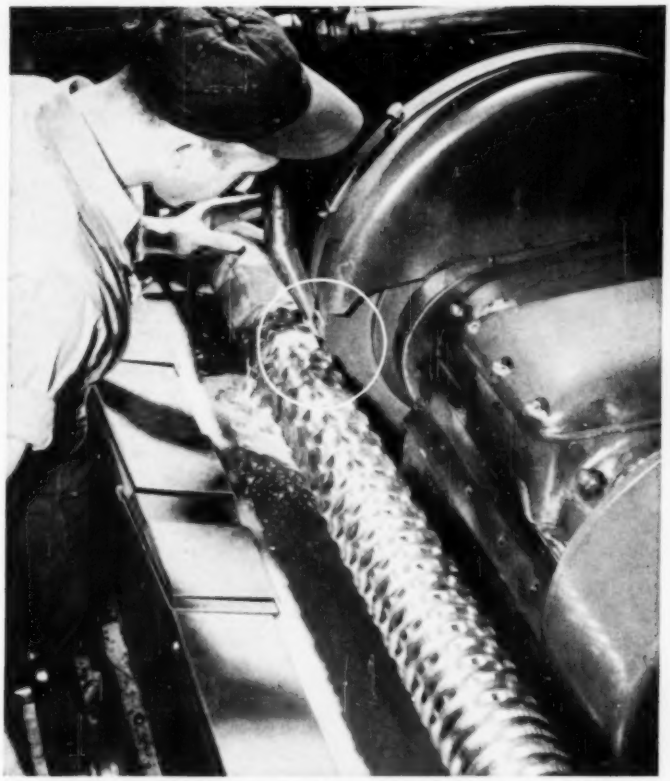

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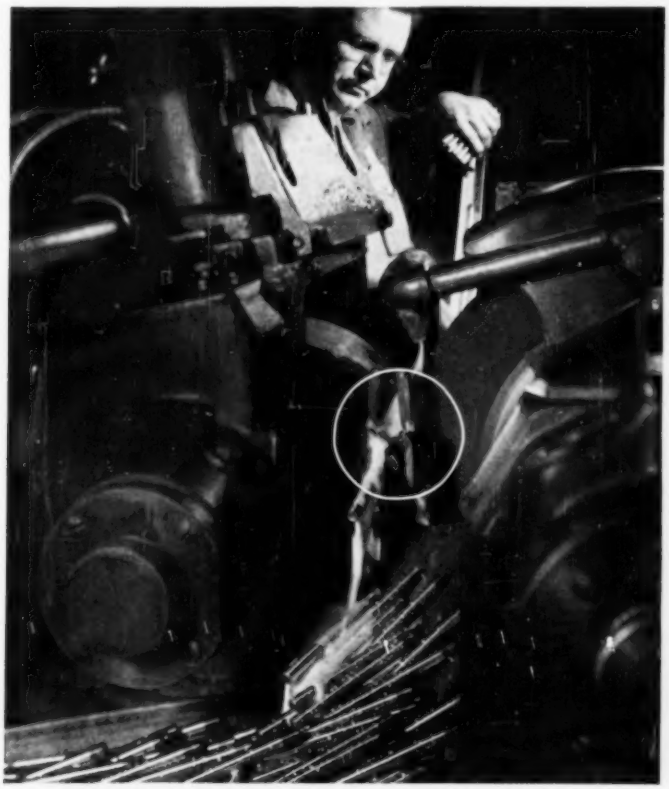

"G Bond Wheels Cut Faster, with twice as many pieces per dressing," says a customer reporting on a centerless grinding application.

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Obviously these do not represent all the possibilities, nor do I believe it typifies the committee's, or the division's final possibilities. Too short a time has passed since the organization of the group to allow much more development.

There are many fields outside the narrower one of electronics. Electrical manufacture, radio, television, lighting and other tubes, circuits, standards, inspection; all of these only typify a few "angles." Communication also includes telephone, telegraph, radios, ranging and other forms of signal transmission. It includes reproduction, as in records, dictating machines, tape recordings, transcribers, and all of the large industry so connected. Note that all of these have electronics as a common denominator. All have a stake in quality control. Members with these interests have serious problems in common.

Business Administration and Operations

Following a preliminary investigation, a steering committee in this field has already been appointed. A technical committee or perhaps a division will undoubtedly result. Let us examine these interests which have often been represented in our speaking programs.

The first field which comes to mind is in office procedures which includes many details, coupled with the companion applications to accounting. Personnel matters are another phase of overall administration. Industrial enigneering provides a fourth subject, while applications in the general field of engineering and in research provide two more classifications. Sales forecasting, production control, and order procedure and accuracy are similar groups. Opinion polls, merchandising and marketing surveys add still further fields.

A whole area in itself is provided by the field of vendor-vendee relations, or acceptance sampling and vendor certification, and this area will require close liaison with similar endeavors in most of the industry groupings already mentioned, as well as in the Military Services Division set forth in the next section as the eighth large group. Since this subject is so basically overlapping and because it must be largely administered as a business operation in general, it has been placed here. This, however, is an arbitrary decision. If the proposed Military Services Division were to become primarily involved in military acceptance sampling and inspection, the general problem of vendor-vendee relations could be allocated to it.

One committee already exists in the area assigned to this grouping—namely, Operations Research. Its character as an administrative guiding and counselling function give this technical committee its most logical assignment in the business group, unless a separate grouping, not necessarily a division, were formed to develop an organization for handling problems of methodology, research, development, and high-level decision functions.

Military Services
or
Vendor-Vendee Relations

The last "phantom" division should deal with military service problems, but with certain limitations. Obviously the military, both severally and collectively, have many statistical problems which would be handled by themselves completely within their own organizations under any and all circumstances. If this group, under perhaps a better name, were expanded to include other government services—federal, state, and otherwise, and in the various public institutions, more fields of discussion would open. In any event, the large field of inspection and procurement sampling, typified by Military Standard 105A and similar official schedules of sampling where civilian co-interest is an added factor, could best be handled here with liaison to the business vendor-vendee group. An alternate is proposed: Call it Vendor-Vendee Relations and include *all* matters of acceptance sampling.

Standards Committee

One present committee has not been placed in the outline of divisions; the standards group cannot be allocated to a single industry, or even to the business group. It should remain as a staff group, available to all, and restricted by none.

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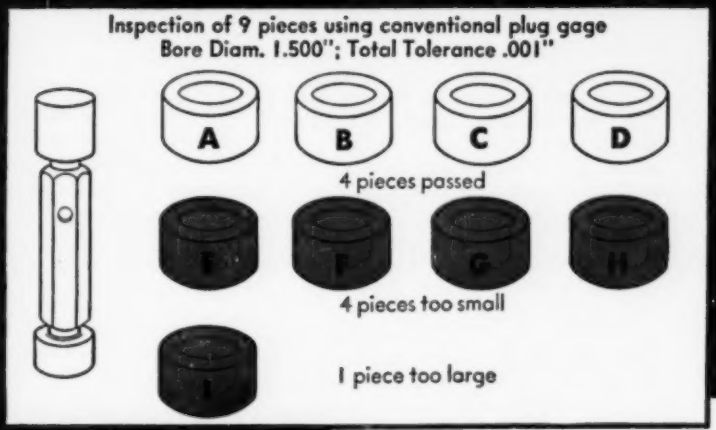

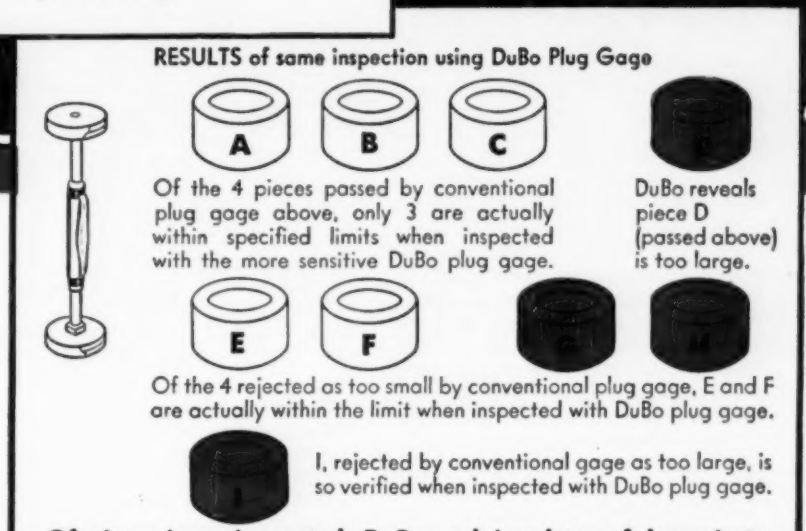
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B
C
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Of the 4 rejected as too small by conventional plug gage, E and F are actually within the limit when inspected with DuBo plug gage.
I, rejected by conventional gage as too large, is so verified when inspected with DuBo plug gage.

Of nine pieces inspected, DuBo reclaimed two false rejects and rejected one piece that had been passed by ordinary plug gage inspection. Apply even a fraction of this ratio to a day's production in your own plant and you'll realize the advantage of using DuBo Plug Gages.

COST-SAVING FACTORS

DuBo Plug Gages outlast ordinary plugs many times. Extremely light in weight (in the larger sizes, 70% to 80% lighter than cylindrical plug gages of equivalent diameter) and requiring no jockeying into position for entry, DuBo effects economies in that important cost item, actual inspection time.

Use DuBo for Precision Plug Economy

When inspecting parts under quality control sampling procedure, it is important that those parts which may be close to either end of the tolerance range be properly classified. The definiteness and simplicity of DuBo gaging is a decided advantage in this type of inspection. Anyone who has tried to enter a cylindrical plug into a hole only .0001" larger than the gage, knows how difficult it is. For even skillful workers there is a point at which it becomes doubtful whether the bore is actually smaller than the gage size, or if it is larger and merely close. With DuBo Plug Gage, even an unskilled worker can easily enter the gage under any condition and quickly interpret bore conditions correctly. There need be no border-line cases of doubt regarding the proper classification of a bore. Use of the DuBo Plug Gage minimizes the cost of parts needlessly rejected and the expense accruing from those incorrectly passed.

TRY DuBo! Sense its craftsmanlike feel and balance. See how easily it enters, even in undersize bores . . . how gentle manipulation of the handle accurately reveals internal conditions. Use it on a *fussy* job and you'll KNOW why DuBo is replacing old time plug gages everywhere! Refer to Catalog C, Pages 18, 19, 20, 21. Or, write or phone for more detailed information.

SUMMARY

This, then, is one man's reading of the desirable growth in the technical phases of our Society—a sort of blueprint for the future. It does not call for the immediate activation of any group, either as a committee, or as a division. Certainly it does list many, but by no means all, of the fields in which statistical control of quality and of evaluation are desirable, and perhaps, in some way, necessary.

No group should be activated until the workers in its sphere of action are both ready and desire it. No group should become a division until it has existed, *and made progress*, as a committee. Once the plan has been settled upon, no group should be activated outside the structure unless so allocated after careful deliberation.

Because this entire subject should be considered from all angles, each member of the Society is invited to express his opinion so that we can be guided by his counsel.

Finally, let it be stated again, this outline is a "phantom" structure, a skeleton, to be given flesh as a matter of growth. Its development as an idea, has taken nearly two years of arranging, tearing down and rearranging. Offering this idea here is not an official act of a society officer, but is the expression of opinion of an independent member for the consideration—and hoped-for approval—of his fellow members in the fastest growing technical society today—a society reaching maturity beyonds its years—and ready for a mature outlook upon its welfare.

The Gage Laboratory, Its Equipment and Function

CLIFFORD A. WALLACE

Eastman Kodak Company, Camera Works

The ascending spiral of finer quality through current methods of quality control depends upon a carefully implemented program of gage control. In any manufacturing process the product can be no better than the tools that produce it, and so it is with quality control, for some of its more important tools are the gages and measuring instruments used by the people inspecting the product.

Excellent design, tools, gages, and organization mean absolutely nothing if those fine qualities are not maintained day in and day out, week after week.

The following will describe the organization, physical set-up, and methods of a gage control group, together with their responsibilities and relationship with other departments.

Gage control is a refined service control after other things have been done; i.e., drawings with proper limits and specifications, good tools and tool controls, and an inspection system such as is found in a proper quality control setup.

Personnel is important. It is essential to have personnel skilled in knowledge of manufacturing methods, tool, die, and gage and fixture manufacture. A surprisingly small force of people can handle a lot of manufacture. At Camera Works we have a ratio of two gage control personnel to 400 operating personnel.

Physical setup requires a central storage of gages, office headquarters, temperature controlled room for sensitive checking equipment, gage vaults for service in manufacturing departments, and mobile or floor units for on-the-job checking.

The first step in setting up a gage control program is to make a complete physical inventory. The very magnitude of the dollar value of the gages involved is the most forceful argument for centralized gage control.

Gages are furnished for particular jobs in singles, pairs, or even more, depending on the size of an order, length of runs, and number of machines in simultaneous operation. They are checked at the machine while in use or exchanged at regular intervals, depending upon the need. Determination of gaging points and types of gages are decided in joint agreement by design, production process, tool, and quality engineers.

Important reasons for establishing a Gage Laboratory are:

(1) to control the accuracy constants built into manufacturing gages and fixtures at great expense

(2) to produce products with interchangeability characteristics

(3) to take advantage of the full manufacturing tolerances and natural wear of the gages for economic reasons

It is doubtful if management ordinarily would consider that the accounting department was doing a good job if it used adding machines and calculating equipment with errors of some three or four percent. Because we know that such would not be tolerated, we have grown to respect the methods of the accounting division whereby each account is carefully balanced. The direct relation to profit and loss statements, the life-blood of any business, is readily seen in accounting. But the same applies to gage control, for policy and organization are essential to control the extreme accuracy required in the gaging equipment.

Camera Works has about 5000 people and about 475 inspection and quality personnel. It has over 200 different products, with 15,000 different parts and hundreds of thousands of different operations. Products range from simple three-dollar cameras to very expensive professional projection and photo-finishing equipment, and a number of government precision items. These frequently involve combinations of mechanical and optical systems, and electronic circuits, and are required to work under almost all conditions found anywhere in the world at any time of year. Accuracies of plus or minus one- and two-thousandths are common. Working limits of one-half thousandth range are frequently encountered. Small, fine-pitch gears and range finder cams which compound effects of inaccuracies are a few examples of the accuracies we control with gages.

If you had visited our factory just prior to 1941 you would have seen the culmination of a gradual change-over. The system of having separate completely specialized factories within a large factory gave

way to one of pooling all of the machine equipment and segregating it into single departments, such as press, milling and drilling, lathe, automatic screw machines, including expensive machines and tooling equipment capable of producing very high grade work. Parts for all products now requiring such machining pass through the same departments. Then they are assembled in separate specialized assembly areas completing the finished product.

Under these circumstances it can readily be seen that standardization in our gage control was indicated. Therefore, it was decided to install a more formal and comprehensive program.

A primary aim was to make sure that the system would channel the gaging equipment in daily use in the many departments of the plant to the gage laboratory for determinations of accuracy. Wear in normal use is, of course, the greatest single factor in making such checks.

In the Camera Works today, all gages are cataloged in a central gage control office. Here the reserve stock necessary for replacements is maintained. General gages, including such items as plain and threaded cylindrical ring gages, various types of indicators, micrometers, verniers, thread and gear wires, and so on, are all stocked in carefully labeled drawers for easy and immediate access. General gages in Camera Works are catalogued and stored by size—not by part numbers. This method releases the entire stock for universal use and avoids unnecessary clerical work.

To this control point equipment checked and accepted by the gage laboratory is delivered for cataloguing, stocking of extra members, and distribution to the ultimate use locations in each of the many machining and assembly departments. Here again, the gages are stored in drawers by size and are issued to the operators with the tools for the job. The tools and gages required for each operation are shown on a department operational sketch.

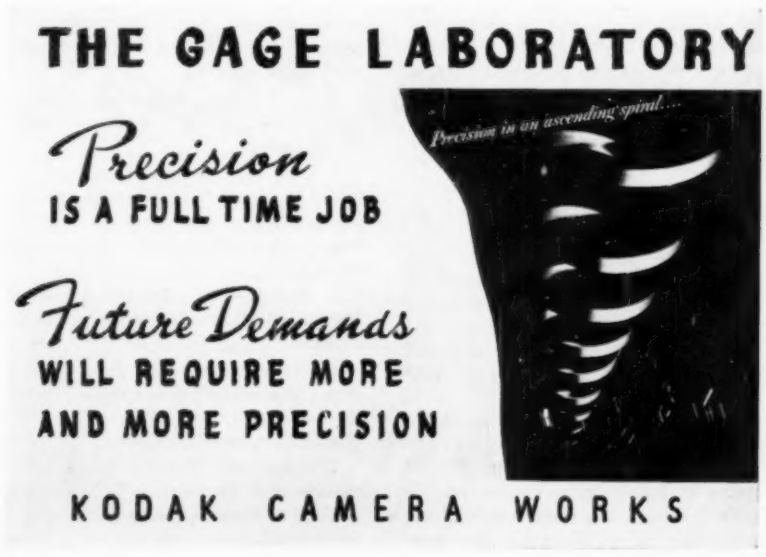
At this point, the "perfect" gage issued to the operator can no longer be assumed to be correct and, of course, the longer he has it and the more he uses it, the less we can feel that it retains its original characteristics. Inasmuch as the great majority of machined jobs at Camera Works are of a short run nature, we have been able to feel secure in allowing gages to remain for the duration of the job or until the end of the shift, depending on which is shorter. At this time when the gages are returned to the tool vault, they are placed in padded trays, rather than back in their storage compartments, and are sent to the gage laboratory for measurement.

In the relatively few cases where jobs run for extended periods, gages are permitted to remain at the machine and are checked there by a traveling gage inspector. His mobile inspection truck is equipped with a supermicrometer, gage blocks, cylindrical standards and thread measuring wires. Built-up or fixture type gages are handled in very much the same manner as standard gages except that frequency of checking is determined by inspection and production supervision based on intimate knowledge of the part and operation. The checking is, of course, done by the gage laboratory.

Camera Works now has in excess of 100,000 gages, with more than 500 thread set plugs. More than half of our general gages are in sizes below ¼-inch, and the great majority of our threads, exclusive of the machine screw sizes, are of the fine pitch variety.

The gage laboratory is the heart of our program. We feel, quite obviously, that precise mechanical control of our gages is essential. We also feel very strongly that these same gages must also be of the type and in the quantities that will be required, and that we must have them for all the dimensions that require them. To accomplish this end we have created a procedure whereby, when new models are released by the design engineers and assigned to process or product engineers for tooling, the gage specialist quality control engineer meets at this point with the process engineer and others, to review the tool layouts and specify the gages which they feel are essential for each operation. These gages are immediately written in on this original layout and become an integral part of it. From this point on, tools and gages are ordered together. Requisitions are written for those which can be purchased as catalog items (this includes all the general gages), while designs are made for those of the built-up type, such as location, flush pin, optical, electrical, etc.

All written orders which are transcribed are routed through the gage engineer for his approval. This serves a dual purpose. It provides a routine double check on the accuracy of the re-written data and stipulation of required quantities in addition to making it possible to observe trends in gage life as reflected by replacement orders. It keeps the gage engineer informed on additional gages which may have been requested by individual departments on current models as a result of specific problems. In brief, no gage can be ordered without the knowledge and approval of the gage engineer. Eventually, the designs



of special gages are sent to the gage engineer for approval. This is an approval of type and suitability rather than a designer's check for accuracy of computations. All this is as it should be since the gage is as much the tool of the inspector as the lathe is of the machinist.

This supervision of the gage engineer over original specifications for and subsequent additions to the gaging equipment has many desirable aspects. Specific policies can be more readily followed, and policed when necessary, because of the required routing of orders and designs.

This is the method that made it possible to enforce the use of universal equipment whenever practical and thus expedite the trend away from the excessive use of fixed, single purpose gages. The advantages of such a policy are many; for example, lower first cost and the tangible reflected economy in tooling costs for a new model. No less important is the immediate availability of equipment that may be purchased. The savings effected by having equipment available, thus eliminating the time lost in designing, building, and checking special purpose gages is somewhat intangible but, nevertheless, parts made without proper gaging on hand when required are not always acceptable. The rejections and consequent loss from this reason are not usually recognized as the result of "gages on order, but not received." The value of relieving the tool room load should by no means be overlooked.

It is inevitable that, with a gage laboratory such as ours, there will be rejected gages. The laboratory people adhere rigidly to the specifications for the gage at hand whether it is a new plug gage or a repaired fixture gage. It is essential therefore that the reports of their findings on rejected new equipment be examined and evaluated and a decision on the disposition of the material be rendered. This also is one of the functions of the gage engineer. He reviews the data and, considering the factors such as need, seriousness of the defects, etc., indicates what disposition should be made in each instance. On purchased equipment this may be to repair either at the supplier's or our own expense, or to return the material to the supplier for correction or replacement. Much of this is done

in close cooperation with the purchasing department.

As is true of so many manufacturing industries today, engaged in government contract work, it is more economical to sub-contract certain components from others who specialize. This sub-contract program is frequently serviced with duplicate gages from our own program or, if the parts are made exclusively by vendors, they are customarily considered in the gage layout and gages are furnished to them which may be returned to our plant for periodic check. The quality control engineers who visit these outside facilities frequently observe the condition and use of gages and recommend checking or replacement if conditions indicate this to be necessary. The responsibility for delivery of gages for sub-contractors rests with the gage control stock group who proceed with this function on the basis of information automatically supplied to them on the tool layouts.

A special group of the gage control section maintains records of all gages delivered to sub-contractors. These are recalled periodically for check. Duplicate gages are supplied to our receiving inspection so that both the sub-contractor and ourselves check to the same standards.

While some of this gaging and testing equipment for gears and optics and electronics is checked by gage control, the more specialized apparatus is handled by the gear engineering department and the optical and the electrical laboratories. Such groups, including the chemical laboratory, etc., cooperate closely with our gage control.

Our present setup provides for coordination of all gages, fixtures, and tools in that jigs, fixtures, and other tools are checked by the tool department, which is located adjacent to gage control. Actual parts produced from such tools are checked, too. Data are available to gage control group and gages are checked to these same standards. Basic reference points are established by engineering department. The entire program is coordinated by the quality engineers, who work closely with process engineers and with gage control.

A gage control department might well be set up with such responsibilities as—

1. Custody and control of all gages for inspection of parts, that is, gages carried in cribs in various manufacturing departments as needed.

2. Custody of pooled standard gages. Responsibility for physical inventory.

3. Responsibility for the accuracy of all gages at all times, and authority to require return of gages for checking where necessary.

4. Gage accuracy to include all mechanical measuring instruments. All are subject to inspection check for accuracy.

Persons drawing gages are to be held responsible for their return except that, on shift work, department supervision may hold gages at machines through different shifts, in which case supervision will be responsible for their return.

Certain special pieces of equipment, normally used in the plant proper, might be mentioned because of their effect on the gage control program.

An example is the Kodak Contour Projector which is built at Hawk-Eye Works. With appropriate glass charts and staging fixtures one can check accurately both hole diameters and locations of the many holes in fuze parts to tolerances in many instances of the order of 0.0006 in. magnitude. This equipment has eliminated the need for literally dozens of the old-fashioned type of sliding pin gages. Here we have something far better and very definitely less expensive. The accuracy of sliding pins is always debatable. By eliminating them in favor of an optical method, one gets more precise results plus a simultaneous hole diameter inspection, thus eliminating hundreds of plug gages. The advantages are obvious.

The system we employ fits our needs and our organization. The system recognizes the design specification limits to be the standard supreme.

From the design specification on the drawing to the creation of a part exactly according to the design specifications, an amazing number of things and people are involved.

It is the growth aspects of an organization in an activity like this, and the over-all perspective that are interesting. Actually, now, our tool and part checking group in our toolmaking department do all of the measuring and checking of gages and operate our temperature controlled gage measurement laboratory. This function started out some ten or more years ago as a separate gage control function. But after first thoroughly centralizing the principal whereabouts of all gages used in the plant, standardizing on all inventory, appointing a gage engineer to maintain the standardization and efficiency of future gage stock supplies, and establishing gage vaults throughout the plant in appropriate manufacturing centers, we have gradually integrated with our tool manufacturing and repair activities the gage control function, our trained specialists, and our facilities to the point where there is now no duplication of effort or space. About the only autonomous person is the quality engineer gage specialist.

Planned or not, the making of parts to dimensions outside specified limits can be traced indirectly to lack of authority and to lack of equipment and organization to maintain accuracy of gages in a plant.

Gage control then, known and practiced at Camera Works, gives us better products and lower over-all cost.

Something of the basic nature of this accuracy maintenance work is illustrated by the experience of a gage control subgroup attached to the Rochester Society for Quality Control. The unit was formed in 1945 after the first Annual Clinic of the Rochester Society. After leading a meeting on "Quality Control through Gage Control," I was asked if those in attendance could meet again. The philosophy of the "quality" of quality control being very dependent upon careful control of the gages touched the key of so active a problem that many wanted to do more about it. Some of the questions were related to gaging policies, standards used, gages for subcontractors, and methods of repairing steel gages.

Since February, 1945, this subgroup has met regularly, and elected officers annually, without interruption. The membership is made up of one to four members from each of our principal industries, among them chief and assistant engineers, quality control department heads, plant superintendents, general foremen, tool department heads, tool room foremen, chief and assistant inspectors, chemical laboratory head, and others from all parts of a company's organization.

Members felt that many phases of this new subject could be developed through group discussions, such as the order in which materials cause wear on gages. The order is: stainless steel; zinc and aluminum die castings; aluminum and plastics; steel; brass. Also discussed was the comparative perishability of gages (cylindrical, plug, ring, etc.) made from alternative types of materials like: steel; chrome plated steel; tungsten carbide (carboloy); alloy of cobalt, chromium, tungsten (Stellite); boron carbide (Norbide); corundum (sapphire); glass. The standards used were U.S. Standards as applied by American Gage Design. Engineering designs for gages should be checked against these standards. This applies particularly to thread forms.

Many specialists in the various phases of gage work have spoken before the group. Some covered such facets of the gage picture as the following: "The Practical Side of Gage Design," "The Unseen Factors in Gages," and "Inspection by Optical Projection Methods." Others covered screw threads, unified threads, and metallurgical aspects of certain problems.

Continuing interest in the group is shown by the regular meetings at which the average attendance is about 40 men. This roughly indicates that the meetings have been and still are of value.

The formation of a similar group might well be considered a beneficial tool for the gage people of any area, who would find as we have in Rochester that the benefits far outweigh the minor inconveniences of operating such a group.

Since the economic factors of the gage control program dictate in many cases the kind of setup installed, it may be of interest to know what we did. To equip a gage laboratory with the items with which we started out, the cost in today's market would be about $60,000—$18,000 of which would be for a Swiss S. I. P. (Societe Genevoise d'Instruments de Physique) Universal Measuring Instrument. A suitable air-conditioned and temperature-controlled room would cost between $30,000 and $40,000, depending on location.

A group of basic instruments to do the careful measuring required in a gage laboratory in our case consisted of: two toolmaker's microscopes; one Universal Measuring Machine and Microscope (S. I. P. ($18,000); one simple microscope; one supermicrometer; one optical comparator; and miscellaneous equipment such as: one small sine plate; several dial comparators; several sets of gage blocks; standard measuring rolls; and the usual small precision measuring tools.

Additional equipment was acquired as rapidly as conditions and deliveries would permit. One addition was an Electro-limit Universal Internal Comparator, thus making possible accurate determina-

tions of fixed gages for internal dimensions. Closely following this, a 48-in. Standard Measuring Machine was acquired. This permits mechanical measurements directly in one hundred-thousandths.

Several more toolmaker's microscopes and a relatively large number of supermicrometers were added. Special benches were designed and built for convenient use of the "super-mikes," since these instruments get a lot of use in a gage laboratory. Routine check of nearly all plug gages—plain, cylindrical and threaded members—as well as thread setting plugs, are made on them. Other toolmaker's microscopes were added, such as the Gaertner. A Vinco Optical Master Dividing Head was obtained and with it the accessory Cam Rise Checker, thus providing a means of making accurate determinations of the various master cams we use as well as some functional machine parts.

Additional equipment, which we have since come to regard as indispensable, was rapidly acquired. It included: monochromatic light source for optical flats; small round super-accurate surface plate; bore gages covering a range of 0.7500 to 6.000 in. inclusive; index master for angular measurements; Cadillac Pla-check; visual gage of the comparator type; sine plate for compound angles; cylindrical standards; and, of course, sets of gage blocks in inspection accuracy as well as a master set of laboratory accuracy; and additional optical comparators.

Surface finish analyzers were also added to the laboratory equipment. Their use over the years has been so beneficial that rejections of gages for unsatisfactory surface finish are now rare. Gages with rough surfaces, of course, have relatively short lives. A small amount of wear removes the high points over which original measurements were made.

These are the essential items which we acquired. Naturally, laboratory measuring equipment requirements vary according to types of products, but a good idea of the problem can be obtained by these comparisons.

There would be a personnel ratio requirement of one gage control person for every 200 production employes, but that would be even less if you already had a good tool checking setup. The cost-wise control of the expenditure for the gages is a proper responsibility function of the production engineer, who is accountable for the tooling and production layout to accomplish the successful manufacture of an item. But the policing of the system for the maintenance of accuracy in the gaging equipment can very properly be the responsibility of a quality engineer gage specialist.

We have found that interchangeability of parts, even on simple low-priced products will lower assembly costs, repairs, and servicing, and that better parts mean less scrap.

Finally, it should not be too difficult to survey the possibilities of a gage laboratory paying for itself in a surprisingly short time. We found that so when we added up the savings accrued when we got together some $800,000 worth of gages and began our standardization program.

A first-rate control system, therefore is necessary

(1) In order to achieve a state of interchangeability of parts

(2) Because complete quality control cannot be achieved without adequate gage control provisions

(3) To get a central stock of standardized gages with accuracy and physical inventory guaranteed

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Bibliography

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ANALYSIS OF VARIANCE

INTERPRET MACHINE VARIATIONS WITH ANALYSIS OF VARIANCE, Norbert L. Enrick
(Textile World—v. 103, n. 7, July 1953, p. 130)

The author describes the concept of variation from the within-machine and between-machine standpoint. Detailed examples of the use of analysis of variance to calculate a "co-efficient of variation" are given.

APPLICATION—AIRCRAFT INDUSTRY

NEW USAF INSPECTION METHOD HALVES COSTS, Fred S. Hunter
(American Aviation—v. 17, n. 4, July 20, 1953, p. 37)

Short description of the application of the Air Force Quality Control surveillance system at various aircraft manufacturing plants in the California area.

APPLICATION—CHEMICAL INDUSTRY

LABORATORY PRECISION AND SPECIFICATION LIMITS, Eugene C. Yehle, University of Michigan
(Analytical Chemistry—v. 25, n. 7, July 1953, p. 1047)

Chemical process companies must consider the variability of their test methods as part of the over-all problem of product variability and control. Methods of rechecking and controlling laboratory analysis through control chart techniques are discussed. Operating characteristics to enable the user to determine the probability of acceptance and rejection of material under given criteria are described. This method is necessary since laboratory examinations do include the risks of accepting material that should be rejected or rejecting material that should be accepted. Rechecks then essentially constitute a double-sampling plan of this material.

APPLICATION—METALLURGICAL INDUSTRY

QUALITY CONTROL TAKES TEAMWORK, Herbert A. Prelinger, General Metals Corp., Burbank, California

(Steel—v. 133, n. 2, July 13, 1953, p. 101)

Some notes on problems in metallurgical and chemical evaluation of metals. Not SQC.

APPLICATION—METAL WORKING

6TH ANNUAL QUALITY CONTROL FEATURE ISSUE, of Tooling and Production—v. XIX, n. 7, October 1953.

This series of articles describes the application of statistical quality control techniques to various industries and their special problems. The descriptions following each article are those presented editorially by Tooling and Production.

QUALITY LEVEL CERTIFICATION, Roscoe Smith, Ford Motor Co.

"Certification is a means of merging the quality program of a supplier with that of his consumer. It clarifies and defines the quality requirements of a purchased product."

QUALITY CONTROL IN THE RECEIVING DEPARTMENT, Joseph J. Manuele, Westinghouse Electric Corp.

"Sampling inspection of components received from the supplier has helped to reduce inspection costs in receiving by as much as 60 percent."

QUALITY CONTROL IN THE PRESS ROOM, Lester F. Spencer, Landers Frary & Clark

"The nature of press room operations requires a flexible planned program to ensure high quality of work produced. Raw material inspection, 'first piece' inspection, and statistical techniques are factors in controlling quality."

THE APPLICATION OF STATISTICAL QUALITY CONTROL TO EXPERIMENTATION, Frank Caplan, Jr., General Electric Co.

"Controlled experimentation determines the relative importance of variability factors. By eliminating those of no significance, and providing an error factor for those of little significance, it was possible in one case to obtain from 180 experiments all the information supplied by 6500 experiments otherwise required.

PROVIDING INCENTIVES FOR IMPROVED QUALITY, H. Dean Voegtlen, Hughes Aircraft Co.

"Frequently workers are not really informed as to just what is wrong with their work or how to improve it, therefore, this company provided an incentive for better quality workmanship in their Quality Control Program."

THE DEVELOPMENT OF A GAGE CONTROL SYSTEM, C. H. Borneman, General Electric Co.

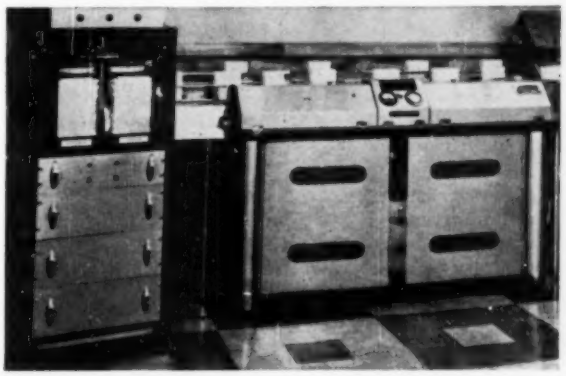
"An adequate gage control system provides for accuracy of gages in use or in storage, scheduled inspection of all gages and master gages, and determination of practical accuracy tolerances."

QUALITY CONTROL OF INVOLUTE SPLINES, A. S. Beam and L. N. DeVos, Vinco Corp.

"Because splines provide multiple locating surfaces, it has been necessary to adopt a dimensioning system peculiar to them."

INSTRUMENTATION FOR STATISTICAL QUALITY CONTROL, W. Hecox and R. L. Merrill, Battelle Memorial Institute

"A system for automatic control of weight is adaptable to control of other physical variables. An automatic control chart plot-



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ter computes averages and ranges, records them instantly, and can be adapted to correct the influence."

FIRST STEPS IN ESTABLISHING A QUALITY CONTROL PROGRAM, Michael P. Agresta, Pesco Products Div., Borg-Warner Corp.

"To successfully establish quality control in a smaller organization, a well planned training program should be established for selling the idea."

THE SWITCH FROM OLD-FASHIONED PRODUCT INSPECTION TO MODERN QUALITY CONTROL . . . CUTS REJECTS AND INSPECTION COST, John M. Sherman, Standard Pressed Steel Co., Jenkintown, Pennsylvania
(Factory Management and Maintenance—v. 111, n. 4, Apr. 1953, p. 138)

A description of the advantages resulting from the establishment of modern quality control (statistical) at Standard Pressed Steel Company. An outline of the changes instituted is presented.

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APPLICATION—MISCELLANEOUS

FORMULA FOR YARN EVENNESS ACCOUNTS FOR CHANCE FACTOR, N. L. Enrick, (Textile Industries—June 1953, p. 193)

Chance factors causing variation in yarn densities are separated from inherent factors. Formulas to express comparative variations are developed.

WOODWORKING APPLICATIONS OF STATISTICAL QUALITY CONTROL, Edward P. McMahon, Mickey Brothers, Inc., Memphis, Tennessee
(National Hardwood Magazine—Part 1, v. 27, n. 6, June 1953, p. 34; Part 2, v. 27, n. 7, July 1953, p. 21)

Describes how SQC techniques are used, in process control, waste and scrap reduction, and acceptance sampling. Applications cover the manufacture of veneer, plywood, and lumber products.

QUALITY CONTROL IN PRACTICE, John W. Greve
(The Tool Engineer—v. XXXI, n. 1, July 1953, p. 68)

The establishment of quality control procedures at the Hoover Company. The use of statistical data, frequency distribution, control charts, etc. to point sources of trouble. Emphasis is placed on the corrective action required to improve product quality.

QUALITY CONTROL OF RESISTANCE WELDING BY STATISTICAL METHODS, J. F. Radford and R. K. Waldvogel, Crosley Div., Avco Manufacturing Corp.
(The Welding Journal—v. 32, n. 6, June 1953, p. 521)

A discussion of the application of statistical techniques to the control of resistance welding. Frequency distributions and control charts are described. An example of the control of a welding operation through control chart techniques is given.

ENGINEERING AND EXPERIMENTS

INCREASING THE EFFICIENCY AND ECONOMY OF EXPERIMENTATION, Edwin C. Harrington, Jr., Monsanto Chemical Co., Springfield, Massachusetts
(Tappi—v. 36, n. 5, May 1953, p. 137)

A factorial arrangement is given as a basic "master" plan for experiment design. This is altered to form simplified plans to fit the technical situation and economics of a given problem. Illustrated with figures of many plans for specific conditions.

STATISTICAL ASPECTS OF SPECIFICATIONS, H. H. Johnson, National Malleable and Steel Castings Co.
(Mechanical Engineering—v. 75, n. 6, June 1953, p. 447)

The author describes the normal frequency distribution and the control chart which is used to represent it. The establishment of specifications based upon the frequency distribution and control chart is discussed.

MANAGEMENT AND PERSONNEL, GENERAL

THE ROLE OF STATISTICAL METHODS IN THE MODERN QUALITY CONTROL PROGRAM, Dr. Carl E. Noble, Kim-

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Statement of the Ownership, Management, Circulation, Etc. Required by the Act of Congress of August 24, 1912, As Amended by the Acts of March 3, 1933, and July, 1946.

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GEORGE R. FOSTER,
Managing Editor

Sworn to and subscribed before me this 28th day of September, 1953.

LILA H. MEANY,
Notary Public

(SEAL)
(My commission expires September 19, 1954)

berly-Clark Corp., Neenah, Wisconsin
(Paper Trade Journal—v. 137, n. 2, July 10, 1953, p. 21)

The importance and role of statistical methods and probability in a quality control program is described. Steps to be taken in the establishment of a modern quality control program are outlined.

HOW TO ATTAIN RESULTS WITH QUALITY CONTROL, W. F. Stryker, Douglas Aircraft Co.
(SAE Journal—v. 61, n. 7, July 1953, p. 37)

This report of a panel discussion at the SAE National Aeronautical Meeting in Los Angeles, October 1952, discusses several problems related to quality control under Air Force contracts. A list of ten results management expects from quality control is also given.

MISCELLANEOUS

QUALITY CONTROL — Savings Effected by an American Company Through the Introduction of Statistical Methods,
(Automobile Engineer—v. 42, n. 561, Dec. 1952, p. 533)

A report of savings realized by the International Harvester Co.

QUALITY CONTROL ON "SHIPPERS" SAVES PACKERS MONEY, H. H. Slawson
(The Glass Packer—v. 32, n. 9, Sept. 1953, p. 25)

The need for realistic specifications, and assurance of quality of accepted material is pointed out in a case history study of corrugated shippers. Not SQC.

SAMPLING PLANS AND RELATED TOPICS

DISCOVERY SAMPLING CUTS COSTS IN QUALITY CONTROL, James R. Crawford, Lockheed Aircraft Corp., Burbank, California
(Iron Age v.—v. 171, n. 5, January 29, 1953, p. 114

Discovery sampling is a simplified quality control system. It meets the needs of the job shop with a large volume of small orders entering production each month.

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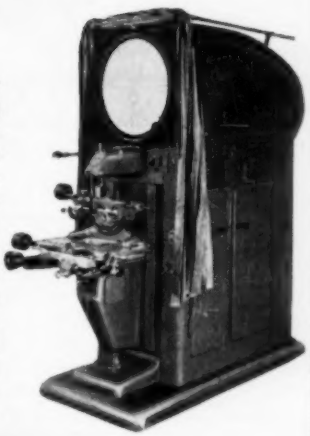

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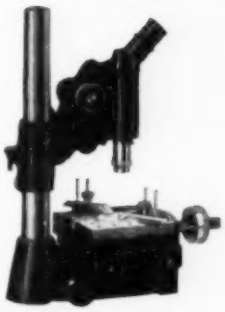

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QUALITY CONTROL FOR GLASS CONTAINERS, Dr. J. H. Toulouse, Owens-Illinois Glass Company
(The Glass Packer—v. 31, n. 11, Nov. 1952, p. 727)

The importance, and some of the technical considerations (AQL, risk, etc.) of acceptance sampling plans are discussed. MIL-STD 105A is described briefly. Illustrated by case histories.

THEORY AND APPLICATION—GENERAL

QUALITY CONTROL THROUGH STATISTICAL METHODS, Norbert L. Enrick
(Modern Textiles Magazine—v. 24, n. 10, Oct. 1953, p. 32)

This article is the first in the series on quality control through statistical methods. It has been designated as No. 3 in the Modern Textiles Magazine Handbook series. This first article describes the basic concept of the frequency distribution and several basic statistics. The harmonic mean is presented as having special significance in averaging certain information with respect to the yarn industry.

QUALITY CONTROL THROUGH STATISTICAL METHODS, II—MEASUREMENT OF VARIABILITY AND ITS USES, Norbert L. Enrick
(Modern Textiles Magazine—v. 24, n. 11, Nov. 1953, p. 43)

The standard deviation and coefficient of variation are described and their calculation illustrated. The use of these statistics and of a table of areas under the normal curve are illustrated.

STATISTICS

THE BASIC THEOREMS OF INFORMATION THEORY, Brockway McMillan
(Annals of Math. Stat.—v. 24, n. 2, June 1953, p. 196)

COMPARISON OF SERIAL NUMBER DIGIT SAMPLING AND SYSTEMATIC AND RANDOM SAMPLING, O. O. Price and A. J. McKeon
(Applied Statistics—v. 2, Mar. 1953, p. 39)

VARIANCE OF A WEIGHTED MEAN, P. Meier
(Biometrics—v. 9, Mar. 1953, p. 59)

SERIAL TEST FOR SAMPLING NUMBERS AND OTHER TESTS FOR RANDOMNESS, I. J. Good
(Cambridge Phil. Soc. Proceedings—v. 49, Apr. 1953, p. 276)

ESTIMATING VARIABILITY FROM THE DIFFERENCES BETWEEN SUCCESSIVE READINGS, J. Keen and D. J. Page
(Applied Statistics—v. 2, Mar. 1953, p. 13)

NOTE ON THE POISSON LAW, R. M. Redheffer
(Mathematics Magazine—v. 36, Mar.-Apr. 1953, p. 185)

EFFICIENCY OF SEQUENTIAL SAMPLING FOR ATTRIBUTES, H. C. Hamaker
(Philips Research Reports—v. 8, Feb. 1953, p. 35)

SEQUENTIAL DECISION PROBLEMS FOR PROCESSES WITH CONTINUOUS TIME PARAMETER — TESTING HYPOTHESIS, A. Dvoretzky, J. Kiefer, and J. Wolfowitz
(Annals of Math. Stat.—v. 24, n. 2, June 1953, p. 254)

OPERATIONS RESEARCH

OPTIMAL HORSE RACE BETS, Rufus Isaacs, The Rand Corporation
(American Mathematical Monthly—v. 60, n. 5, May 1953, p. 310)

The author develops a mathematical solution to the problem of placing straight win bets on a horse race so as to maximize expected profit. Incidentally, as the author points out, this problem is akin to the current field of nonlinear programming.

REPORTED—NOT REVIEWED

TESTS INVOLVING SEVERAL VARIABLES, O. Redlich and F. R. Watson
(Aeronautical Engineering Review—v. 12, June 1953, p. 51)

STATISTICAL APPROACH TO A PROBLEM OF CHEMICAL MANUFACTURE, A. Muir and F. Downton
(Applied Statistics—v. 2, Mar. 1953, p. 30)

CURRENT DISTRIBUTION IN BARREL PLATING—A STATISTICAL SUDY, William C. Geissman and Robert A. Carlson
(American Electroplaters' Society, Proceedings—v. 39, 1952, p. 153)

A STATISTICAL THEORY OF ORDER-DISORDER EQUILIBRIUM AT HIGH TEMPERATURES, Philip Schwed and Gerhart Groetzinger
(Journal of Chemical Physics—v. 21, June 1953, p. 963)

ANALYZING STRAIGHT LINE DATA, F. S. Acton
(Journal of Chemical Education—v. 30, Mar. 1953, p. 128)

STATISTICAL QUALITY CONTROL—A NEW TOOL FOR THE ELECTROPLATER, Ezra A. Blount
(Plating—v. 40, Aug. 1953, p. 868)

SHEWHART MEDAL NOMINATIONS

This is a reminder that Jan. 31, 1954, is the deadline for sending in your nominations for the 1953 Shewhart Medalist who will receive the award at the St. Louis Convention of the Society in 1954. The committee has expressed the considerations on which nominations should be based, as follows:

"Outstanding contributions to the science of quality control, successful promotion and management of quality control programs, and service to the art and to the Society are among the factors which should be considered in selecting nominees."

Nominations for this award are invited from members of the Society, groups of members or sections. Membership in the Society is not required for eligibility and it is desirable that nominations be made with broad national and international scope rather than on a sectional basis.

Responsibility for selecting a medalist rests with the Shewhart Medal committee, but the committee welcomes wide-spread interest and assistance and urges the membership to name suitable candidates before the Jan. 31, 1954, deadline date for such nominations. The names of all nominees should be sent to the chairman of the Shewhart Medal committee:

Maj. Gen. Leslie E. Simon
Office Chief of Ordnance
Washington 25, D. C.

Local Section News

". . . BUT NOT FORGOTTEN"

ALBANY This section held its last meeting on Nov. 10. Prof. Lee S. Crump who was scheduled to talk on "Design of Experiments" was unable to make it. In his place Dr. J. H. Davidson, General Electric Co., spoke on statistical methods. This meeting was held jointly with the Albany chapter of ASA.

ALBANY Berkshire An all-day educational clinic was conducted by this group on Nov. 20, at the Sheraton Hotel in Pittsfield, Mass. Dr. Carl Noble, Kimberly-Clark Corp., served as moderator for the sessions which were devoted to discussing statistical methods for the paper industry.

BUZZARDS BAY At the Nov. 17 meeting of this section John B. Lathrop, Arthur D. Little, Inc., spoke on the subject "Operations Research In Industry."

CHICAGO The second regular meeting of this section convened at 2:30 p.m. Nov. 18 at the Furniture Mart. The theme of this meeting was consumer-vendor relationship—chosen particularly since it was a joint meeting with the Purchasing Agents Assn. G. L. Mydill led off with a detailed analysis of supplier-consumer relations as practiced in his own organization, Motorola, Inc. Richard H. Goodemote and Robert W. Peach, both of Sears, Roebuck & Co., told how Sears is furthering vendor certification. After dinner Conrad R. Dreiske, Hudson Screw Machine Co. and a vice president of the Purchasing Agents Assn., spoke on "Quality Control As It Affects Purchasing."

The 8th Annual Two-Day Training Program in Quality Control for Management was held at the Hotel Sherman on Nov. 19 and 20. This program was co-sponsored by this section and the Chicago Assn. of Commerce and Industry. The conference was attended by 270 satisfied persons (0 persons reported dissatisfied). Instructors for the course were John A. Henry, University of Illinois; Lloyd W. Knowler, State University of Iowa; and Gale W. McElrath, University of Minnesota. The program was presented in 14 one-hour sessions and covered control charts and acceptance sampling.

The opening meeting of the Advanced Educational Sessions was held at the Navy Pier Branch, University of Illinois, on Dec. 2. An excellent, well presented discussion of confidence limits and reliability was given by Dr. Lucille Derrick of the university. She presented a very simple chart from which the confidence limits for the population parameter could be read with the value of the sample statistic given, or vice versa. The second half of the meeting, on the subject of comparing averages, was presented by Ralph Haertel, Stewart-Warner Corp. He used several methods to test for significant difference between two averages, including a novel test based on the control chart.

CINCINNATI A most interesting and enlightening address was heard by the members of this section at the Nov. 18 meeting. The speaker was Julian H. Toulouse, Owens-Illinois Glass Co., who presented the subject "Finding the Facts Before Setting the Specification."

CLEVELAND At the Nov. 6 meeting of this section Robert L. Hermann, A. O. Smith Corp., spoke to a group of approximately 150 members and guests on the subject "Quality Control for Shop Personnel."

A joint meeting with the Cleveland chapter of ASA was held on Dec. 4. Following the dinner, Mason E. Wescott, Rutgers University, spoke on "The Six C's of Simple Correlation."

On Nov. 19 the section was treated to a plant tour of the American Greetings Corp., covering all the operations pertinent to greeting card manufacture. One of the points of interest was the new quality control testing laboratory which was established for testing paper and other materials that are used in the process.

The short course in statistical methods of quality control which is being sponsored by this section is proving to be quite a success. Wendell Abbott, Lamp Div. of General Electric Co., is presenting the course to approximately 50 people from the Cleveland area.

DELAWARE "Installing A Complete Quality Control Program In Industry" was the title of the talk given by Wayne M. Biklen, American Safety Razor Corp., at the Dec. 3 meeting.

DENVER The December meeting of this section was prefaced by Leon Bass, treasurer of ASQC, with a message concerning the policies and affairs of the Society.

The featured speaker, Roy A. Wylie, Micro Switch Div. of Minneapolis-Honeywell, spoke on SQC projects for problem solving. Illustrating his talk with slides and in-process models of mercury switches, Mr. Wylie presented both the routine uses of quality control and those uses which necessitate statistically designed experiments such as analysis of variance and tests of significance.

Both speakers pointed out that the first small sample of Denver weather indicated snow and ice, but all the members assured the two visitors that the sample size, one day, was not statistically sound.

ERIE The Nov. 10 meeting of this section turned out to be something of an unscheduled milestone. The speaker for the evening was Ralph E. Wareham who spoke on the subject "Managing Your Quality Control Program."

The unscheduled part of the program, which consisted of the formal signing of the section's charter, was brought about by some fast work on the part of the chairman, Edward R. Hoffman. Capitalizing on the fact that the charter had been signed by Ralph Wareham as the president of ASQC in 1949 and that further he was going to present the program at the Nov. 10 meeting, Chairman Hoffman contacted the 1949 section officers and invited them to attend this meeting for a formal signing and presentation of the charter. This was no small feat since the chairman, Ned Miles, had been transferred to General Electric's Appliance Park at Louisville while the secretary, B. J. Walker, was still in Erie but no longer in quality control work. Fortunately both men were able to attend so that the formal signing and presentation ceremony turned out to be a most memorable occasion.

On Dec. 1 the section held its annual Management Night. This meeting featured a talk by A. V. Feigenbaum, General Electric Co., on "Quality Control As An Effective Management Method." A special feature of this meeting were book matches emblazoned with the Society's name and a "Quality Control Message" which were passed out as souvenirs of the evening.

HARTFORD Edward S. Marks, Pratt & Whitney Aircraft, spoke at the Oct. 21 meeting on the subject "Management of Quality Control."

The Nov. 18 meeting featured "Controlling the Quality of Screw Threads With Variable Type Gaging" by John M. Sherman, Standard Pressed Steel Co.

INDIANAPOLIS This section's last meeting on Nov. 17 was divided into two separate meetings. The first session, consisting of a chalk talk by Irving W. Burr, Purdue University, was held in the afternoon at the Indiana World War Memorial. The evening session convened in the new auditorium of the Indiana State Board of Health building, where Mason E. Wescott's talk entitled "Statistical Quality Control In India" was premiered for the first formal presentation.

LOS ANGELES This section held a joint meeting with the Los Angeles chapter of ASA on Dec. 2. The guest chairman, Raymond Lichty, Southwest Division manager for government sales, General Electric Co., introduced the speaker for the evening, Leon Bass, General Electric Co., Syracuse. Mr. Bass related some of his experiences in applying quality control methods to the manufacture of electronic parts in general and to diodes in particular.

MICHIGAN Dr. J. M. Juran, management consultant, New York University, presented a timely talk on "Success and Failure in QC Programs" at the Nov. 13 meeting.

The second "out-state" meeting of the year was held at the Sutherland Paper Mill Auditorium, Kalamazoo, on Nov. 20. Brainerd E. Sooy, Gardner Board and Carton Co., spoke on "Application of SQC in the Boxboard and Printing Industry." The meeting was well attended by interested non-members as well as members in the area.

MILWAUKEE The Nov. 23 meeting of this section featured Thomas Lucas, Globe Union, who presented a very interesting talk on "Correlation Analysis for Wage Incentives."

MUNCIE Members of this section are still talking about the meeting we had just before Thanksgiving. Leo R. Harrington, King-Seeley Corp., presented an address entitled "Quality Concepts and Their Effects on Quality Control." It was strictly an edge-of-the-chair affair as an entire new pattern of facts marched across the evening—first the neat parade formation of theory and then the rugged, uneven fighting formation of working facts that actually slug it out in the shop. Many experienced members of the section expressed the hope that more—much more—will be heard of Mr. Harrington's concept of what can happen to engineering limits under the "new accuracy" achieved by quality control.

Here's an item that's not strictly true! Monday, Nov. 30, marked the close of this section's ten-week course in quality control methods. Several other top-notch courses in many different fields were offered in Muncie by various universities and organizations at the same time our QC course was available—nearly a dozen had to be dropped because of lack of students and none reached the fifty mark—our QC course lacked only a quartet of drawing a hundred. Looks like this trend makes its own prediction for '54. (If you are wondering where the untruth is here, see the Muncie item under "As Ye Sow.")

Footnote to Courage. It happened this way: Once upon a meeting in Muncie we had two out-of-town visitors. One was the speaker; one wasn't. The speaker presented a startling theory of QC procedure. Came the question session and, of course, first pop out of the box, someone asked, "What kind of outgoing quality do you get with this deal? What do your customers think of your quality?"

"That gentleman with the pipe, in the third row," answered the speaker, "is one of our biggest customers. I'll let him answer that question." Courage? Amen. And confidence in his program, too. The reply, incidentally, was very favorable. Come to think of it, a better title for this item would have been, "Would *you* be game?"

NEW HAVEN The speaker at the November meeting was Dorian Shainin, Rath & Strong, Inc., who spoke on "How Management Can Cut Costs Through Statistical Engineering." The meeting was very well attended by members and guests from the area management.

PARKERSBURG Dr. Loring G. Mitten, Ohio State University, spoke to 40 members and guests at the Dec. 2 meeting. His topic was "The Nomograph—Little Brother of The Giant Brain."

PHILADELPHIA The joint meeting with the Standards Engineers' Society on Nov. 20 featured August B. Mundel, Sonotone Corp. Mr. Mundel presented some vendor problems which had been solved by the use of narrow-limit gaging procedures. His presentation was illustrated with slides and a lively discussion period followed—always a good barometer of audience interest.

RACINE Forty members of the section were treated to an informative movie presentation on the techniques of air gaging at the Nov. 6 meeting. John McCoy, Sheffield Corp., assisted by Sheffield's Milwaukee representatives, showed two movies after which a

discussion period brought out further applications and details of the technique.

Alvin Morgenroth, section chairman, announced that a panel discussion group would be formed to present the principles and possibilities of a quality control program at a spring meeting of the Racine Works Managers' group.

ST. LOUIS This section extended a cordial invitation to the St. Louis groups of the American Institute of Industrial Engineers and the Society for the Advancement of Management to hear a talk on "Work Sampling" by Dr. Gerald Nadler, Washington University. All three Societies were well represented at the meeting which was held on Nov. 20.

On Nov. 6 the executive committee of the section passed a motion to establish and promote a training course on Special Techniques of SQC.

SAN FRANCISCO BAY AREA This section held a dinner meeting on Dec. 7, at which Leon Bass, General Electric Co., was the guest speaker. Mr. Bass explained the quality control organization in his company and gave examples of specific applications of quality control techniques in a mass production operation (manufacture of germanium diodes) and in a jobshop operation (manufacture of television transmitter equipment).

SOUTHERN CONNECTICUT The Nov. 18 meeting of this section was devoted to a special Management Night program. Albert E. Diem, vice president of manufacturing, Dictaphone Corp., addressed the meeting on "Quality Control and Management." The meeting was so well received and attended—175—that it is planned to make this meeting the first of a series of annual management nights.

SOUTH TEXAS On Thursday, Nov. 19, at the regular meeting of the section, Charles W. Eichbaum, EMSCO Derrick, and Charles F. Lewis, Cook Heat Treating Co., presented an entertaining skit. The skit consisted of the presentation of a typical production problem and the demonstration of the use of industrial statistics in arriving at a solution.

On Friday, Nov. 20, a special joint meeting was held with the local chapters of ASTM, AIChE, and ASC. This meeting was a plant tour of the Tennessee Alloy and Chemical Corp., and a talk entitled "An Excursion in Petroleum Chemistry" by Frederick D. Rossini, Carnegie Institute of Technology.

SYRACUSE J. Alfred Davies, General Electric Co., Owensboro, Ky. electron tube plant, was the guest speaker at the Nov. 24 meeting. In his talk, "How Reliable Is Your Life-Test Procedure," Mr. Davies discussed the merits of three types of sampling plans used in life testing radio tubes.

TORONTO On Nov. 25 the members of this section toured the plant of York Gears, Ltd., Toronto. York specializes in the manufacture of small, high-precision machined parts.

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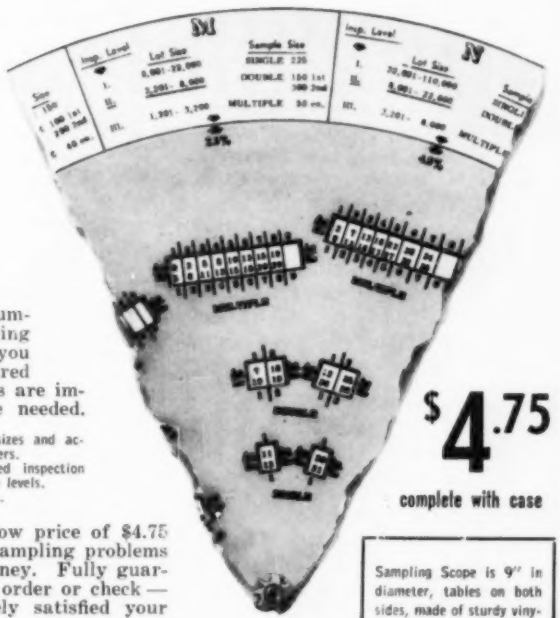

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CALENDAR OF MEETINGS -- JANUARY 20, 1954 -- FEBRUARY 19, 1954

SECTION	DATE	MEETING PLACE	TIME	SUBJECT	SPEAKER
Albany	8	———	——	Operations Research	S. Littauer, Columbia University
Allentown-Bethlehem	21	———	——	Process Capability Studies and QC	Panel discussion
Baltimore	20	Park-Plaza Hotel	——	Increasing the Efficiency and Economy of Experimentation	E. C. Harrington, Jr., Mosanto Chemical
Buffalo	25	University of Buffalo	——	SQC Mission to India	M. E. Wescott, Rutgers University
Central Illinois	——	———	——	No meeting scheduled for this period	———
Chicago	20	Furniture Mart	2:30	QC in the Process Industries	R. I. Tenney, J. Barrabee, H. Sagen
Cincinnati	20	Engineering Soc. Hq.	8:00	Joint with AIChE: "Experiments in the Chemical Plant"	J. A. Mitchell, Tennessee Eastman Co.
	30	Engineering Soc. Hq.	——	Third All-Day Conference: "Practical QC for Management"	———
	17	Engineering Soc. Hq.	8:00	SQC in the Paper Boxboard and Printing Industries	B. E. Sooy, Gardner Board & Carton Co.
Cleveland	5	Cleve. Engineering Soc.	6:30	Tolerance Accumulation Problems	Dorian Shainin, Rath & Strong
Columbus	20	North American Aviation	7:30	Special Problems Encountered in Aircraft QC	H. S. Rankin, North American Aviation
	17	GM Ternstedt plant	6:30	Panel discussion	Max Astrachan, L. G. Mitten
Dallas-Ft. Worth	11	Arlington State Coll., Engr. Bldg.	——	Chemical Process Control	W. S. Hay, Consolidated Vultee Aircraft
Dayton	20	Nat'l Cash Register Co., Audit.	8:00	Quality Concepts and Their Effects on Quality Control	L. R. Harrington, King-Seeley Corp.
Delaware	4	Hob Tea Room	6:30	Process Control in Chemical Operations	L. M. Debing, Monsanto Chemical Co.
Denver	9	———	——	Beyond the Control Charts	R. H. Blythe, USAF
Erie	3	———	——	SQC in the Plastics Industry	R. C. Boyd, Bakelite Co.
Hartford	20	Rockledge Country Club	6:30	QC More Than 50 Miles from Home	Dorian Shainin, Rath & Strong
	17	Rockledge Country Club	6:30	Panel discussion: Instrumentation in Quality Control	Moderator: P. H. Embleton, Veeder Root, Inc.
Huntsville	20	———	7:30	Some Fundamentals of Sequential Sampling	I. Miller, Redstone Arsenal
Indianapolis	16	Ind. St. Bd. of Health Bldg.	7:30	Quality Problems and Approaches to Their Solutions	W. P. Goepfert, ALCOA
Larsdale	11	———	——	———	W. T. Rogers, National Tube Div.
Los Angeles	17	Roger Young Auditorium	6:00	Statistical Applications in Accounting	Rowland Roy, Booz, Allen, Hamilton Co.
Louisville	8	———	——	Annual Dinner Meeting	———
Metropolitan	——	———	——	No meeting scheduled	———
Michigan	5	Wayne Univ., Science Hall, Detroit	——	What Is Your Problem?	Panel discussion
Middle Atlantic Region	5-6	Lord Baltimore Hotel, Baltimore	——	Middle Atlantic Quality Control Conference	———
Milwaukee	25	Marquette Univ., Bus. Adm. Bldg.	7:30	SQC Can Help Engineers	Dorian Shainin, Rath & Strong
	3	Wisconsin Hotel	9:00 am	Industrial Clinic for Quality Control	———
Minnesota	12	———	——	Social Evening	———
Montreal	27	———	——	Specifications and Tolerances	B. H. Steeves, Northern Electric Co.
	10	———	——	Some Statistical Applications in Pharmaceutical Mfg.	R. M. Hofstead, Bristol Laboratories
Muncie	28	Pittenger Student Center	6:30	Tests of Significance in Industrial Processing	G. G. Parkin, Minnesota Min. & Mfg. Co.
New Haven	11	Chamber of Commerce Audit.	——	Methods of Control of In-Process Inspection	G. A. Morse, Wico Electric Co.
Northeastern Indiana	11	———	——	———	H. P. Koogle, General Electric Co.
Parkersburg	2	Chancellor Hotel	8:00	Organization and Scope of SQC	W. J. Chelgren, E. I. duPont
Philadelphia	29	Franklin Institute	4:30	Quality Problems in Life Testing	R. F. Drenick, RCA Victor Div.
Pittsburgh	26	Sheraton Hotel	6:30	QC Applied to Continuous Processes	J. F. Occasione, American Steel & Wire

SECTION	DATE	MEETING PLACE	TIME	SUBJECT	SPEAKER
Rochester	2	———	——	Stat. Techniques Subgroup: Life Testing	B. Epstein, Wayne University
	16	Chamber of Commerce Bldg.	——	Tenth Annual Quality Control Clinic	———
Rock River Valley	25	Lafayette Hotel, Rockford	——	Engineering Design Meets QC To Save Cost	Dorian Shainin, Rath & Strong
St. Louis	19	———	——	Anniversary Meeting: Looking Ahead with ASQC	A. L. Davis, Rochester Inst. of Tech.
San Diego	8	Convair Aircraft—Bldg. 19	7:30	Presentation of a Modern QC System	G. A. Covington, Consolidated Vultee Aircraft
San Francisco Bay Area	8	———	——	Cost Reduction Through Quality Control	E. L. Grant, Stanford University
Southern Connecticut	10	———	——	Incentives and Quality Control	W. M. Bicklen, American Safety Razor Co.
St. Univ. of Iowa	21	Englehart Mfg. Co., Davenport	7:30	Plant tour: "QC for Short Runs"	W. Eckerlebe, Englehart Mfg. Co.
	18-19	Silas Mason Co., Burlington	——	Plant tour and technical sessions	———
Syracuse	26	———	——	What's Your Problem?	Panel discussion
Textile Division	4-6	North Carolina St. Coll., Raleigh	——	Fifth Annual Textile Quality Control Conference	———
Toronto	27	Canadian General Electric Co.	——	Plant tour	———
	10	McMaster Univ., Hamilton	——	Quality Control of Tubular Steel Products	W. T. Rogers, National Tube Co.
Trenton	9	Rider College	8:00	Quality Control in Action	Arthur Bender, Jr., Delco-Remy Div. GMC
Utica	21	Grace Church Parish House	6:30	The Scope of Quality Control	W. R. Purcell, Rath & Strong
	18	Grace Church Parish House	6:30	Quality Control as a Management Method	A. V. Feigenbaum, General Electric Co.
Washington	27	New Athens Restaurant	——	Economic and Marketing Implications of QC	R. I. Tenney, Wahl-Henius Institute
Western Massachusetts	9	Sheraton Hotel, Springfield	6:00	SPAN plan	L. A. Seder, QC Consultant
Worcester	21	———	——	Quality Control Does the Job	W. R. Weaver, Republic Steel Co.

WORCESTER Dr. Ellis Ott, Rutgers University, spoke at the November meeting of this section on "Basic Concepts." Many members and guests from the Worcester area representing ten different and diversified industries attended. Dr. Ott's talk was illustrated with many practical demonstrations.

"... CAST THEIR SHADOWS BEFORE"

BALTIMORE On Jan. 20, 1954, will be the second dinner meeting of this season with E. C. Harrington, Jr., Monsanto Chemical Co., as the speaker. Mr. Harrington's subject will be, "Increasing the Efficiency and Economy of Experimentation." This meeting will be held at the Park Plaza Hotel.

CHICAGO The third regular meeting of the section will be held Wednesday, Jan. 20, at 2:30 pm at the Furniture Mart. The theme for this meeting is Quality Control in Process Industries. Three speakers have been lined up to give what promises to be an excellent program: Robert Tenney, Wahl-Henius Institute; James Barrabee, International Harvester; and either Dr. Harry Sagen or Karl Bauer of Abbott Laboratories.

The next meeting in the Advanced Education Program is to be held at Navy Pier at 7:30 Feb. 3. The subject for this session is significant differences. This is a continuation of the general subject of analysis of variance which was chosen as the over-all theme for the advanced program. Visitors are welcome.

The Basic Training Program will continue with its third meeting on Feb. 17 at 7:30 at Navy Pier. Control Chart Techniques is the subject to be discussed by G. Anderson and H. Gierke. This meeting is to be a combination lecture, discussion and laboratory session.

CLEVELAND On Feb. 5, 1954, this section will hold its monthly meeting at the Cleveland Engineering Society. Dinner will be at 6:30 and the business meeting will begin at 8:00.

The speaker of the evening will be Dorian Shainin, Rath & Strong, Inc., who will talk on "Tolerance Accumulation Problems."

DAYTON Leo R. Harrington, King-Seeley Corp., will address this section on Jan. 20, 1954, at 8:00 at the National Cash Register Company Executive Auditorium. His subject will be "Quality Concepts and Their Effects on Quality Control."

DELAWARE At the next meeting on Feb. 4, 1954, L. M. Debbing, Monsanto Chemical Co., Plastics Div., will discuss "Process Control in Chemical Operations."

ERIE R. C. Boyd, Bakelite Co., will offer "Statistical Quality Control in the Plastics Industry" at the meeting on Feb. 3, 1954.

HUNTSVILLE This section will hold a meeting on Wednesday, Jan. 20, 1954, in Huntsville. The specific meeting place is still open. Pfc. Irwin Miller, Testing and Evaluation Div., Redstone Arsenal, will be the speaker. Mr. Miller will have for his topic, "Some Fundamentals of Sequential Sampling."

MICHIGAN On Feb. 5, 1954, will be the annual "What Is Your Problem?" program. This perennially popular feature of our program year will be held in the Wayne University Science Hall, Detroit. A panel of six local members, well-informed in the various aspects of SQC, will suggest answers to questions submitted either ahead of time or directly from the audience.

MILWAUKEE The January, 1954, meeting of this section will be honored by the executive secretary of ASQC, Dorian Shainin, Rath & Strong, Inc., who will present "SQC Can Help Engineers." The meeting will be held at the Marquette University, College of Business Administration Bldg. on Monday, Jan. 25, 1954, at 7:30. Our usual open forum session will be held at 4:30 preceding the meeting.

MINNESOTA On Friday, Feb. 12, 1954, this section will hold its first social evening. This is a new endeavor this year planned specifically to help bring the membership of the section closer together. The affair will be held at one of the local breweries. It is rumored that many of the members have worked up some pet sampling plans to try out.

MUNCIE This section will start the new year with a meeting in the Pittenger Student Center on Thursday, Jan. 28, 1954, when Guy G. Parkin, Minnesota Mining & Manufacturing Co., will talk at 7:30 on "Tests of Significance in Industrial Processing." The speaker's meeting will be preceded as usual by a 6:30 dinner meeting.

PARKERSBURG William Chelgren, E. I. duPont de Nemours, will speak at the February 2, 1954, meeting on the subject, "Organization and Scope of Industrial Quality Control."

PHILADELPHIA The regular monthly meeting will be held on Friday, Jan. 29, 1954 at the Franklin Institute. Dr. R. F. Drenick, RCA, will speak on "Quality Problems in Life Testing." Our extra feature, the problem clinic, will feature T. Moran, Wyeth, Inc, who will lead a discussion on "Application of Quality Control in the Chemical Industry."

SAN FRANCISCO BAY AREA The next general meeting of this section will be held on Feb. 8, 1954. At this meeting Prof. E. L. Grant, Stanford University, will address the section on the subject, "Cost Reduction Through Quality Control."

SOUTHERN CONNECTICUT On Feb. 10, 1954, Wayne M. Bicklen, American Safety Razor Co., will address the section on "Incentives and Quality Control." A special invitation to this meeting is being sent to time study, and methods people in this area.

TORONTO On Jan. 27, 1954, this section will visit the Dufferin Works of the Canadian General Electric Co.

The Feb. 10, 1954, meeting will be held at McMaster University, Hamilton. W. T. Rogers, National Tube Co., will speak on "Quality Control of Tubular Steel Products."

WESTERN MASSACHUSETTS On Feb. 9, 1954, at 6:00 at the Sheraton Hotel, Springfield, Leonard A. Seder, QC consultant, will give a talk on his SPAN plan, which relates to a method for effective trouble-shooting on process control problems. An "Idea Session" will precede the meeting and will start at 5:15.

"AS YE SOW . . ."

CINCINNATI On Jan. 30, 1954, this section will hold its third annual conference entitled "Practical Quality Control for Management." This conference will be held at the Engineering Society Headquarters in Cincinnati.

The program will include a keynote address by J. G. Pleasants, vice president of Proctor & Gamble Co.; "Quality Control Organization Plan" by E. H. Robinson, Johnson & Johnson Co.; "The New Look" by W. S. Oliver, Detroit Gear Div. of Borg-Warner Corp.; and "How Quality Control Helps Supervision" by E. L. Fay, Deere & Co.

Several quality control exhibits will be on display and a series of quality control films will be shown.

Registration fee for the conference is $3.00; the luncheon is $2.00. L. R. Zimov, Crosley Div. of AVCO Manufacturing Co., Evendale, Cincinnati, is special events chairman for the conference and should be contacted for any additional information.

GEORGIA TECH A statistical quality control short course will be conducted at the Georgia Institute of Technology, Mar. 10 through Mar. 18, 1954. This will be a basic course of intensive training to acquaint industry personnel with techniques for putting SQC into operation.

The staff for this course will include J. J. Moder, R. A. Hefner and D. S. Holmes of the Institute and A. C. Cohen, University of Georgia.

For information write to Coordinator, Short Courses and Conferences, Georgia Institute of Technology, Atlanta.

MIDDLE ATLANTIC QC CONFERENCE The Lord Baltimore Hotel in Baltimore, Md., will be the headquarters for the 1954 two-day Middle Atlantic Quality Control Conference on Feb. 5 and 6, 1954. This year's conference is built around the theme "Quality Control—What It Is and What It Does."

The program will consist of presentations by some 33 speakers handled by 16 moderators. In addition four panel discussions are planned to run simultaneously throughout the two days. One panel is devoted entirely to Basic Concepts of quality control (What It Is); another is devoted exclusively to Practical Applications in eight different types of industries; the third will deal with Special Techniques such as ranking methods, lot plot, etc.; and the fourth covers Attributes Sampling Plans (MIL-STD 105A), Continuous Sampling Plans, Management Aspects of Quality Control, and other subjects.

There will be many special features. Governor Theodore R. McKeldin of Maryland will speak at one luncheon. He is a nationally known speaker, being the man who made the nomination speech for President Eisenhower. At the second luncheon guests will be entertained with a one-act play entitled "Sampling Inspec-

tion," written and performed by the members of the Allentown-Bethlehem section. There will be a fellowship night on Friday night at which a good time and refreshments will be supplied.

The conference is being presented through the joint efforts of the 11 sections in the Middle Atlantic Region. General chairman of the conference is G. R. Page, Western Electric Co., 2500 Broening Highway, Baltimore. Requests for further information about the conference should be directed to him.

MILWAUKEE The one-day Industrial Clinic for Quality Control will be held this year on Wednesday, Feb. 3, 1954, at the Wisconsin Hotel.

In addition to the session devoted to elements of SQC, the program will feature talks on the following eight major areas of application: Food processing, bottling and brewing, leather and shoe manufacture, foundry, metal processing, metal finishing, industrial engineering and market research.

MUNCIE This section's ten-week course in quality control methods has ended and yet it hasn't ended! Although the course was officially completed in November, the students clamored for more, so arrangements are being tentatively made for several supplementary lectures. D. G. Browne, the instructor who brought forth this "encore" for himself and QC, is exploring the possibility of paying off this promise in late January or early February. Phases of QC selected by the students after living for several weeks with their new-found knowledge will be rehashed together with the presentation of some new material garnered from the Midwest Conference last fall.

ROCHESTER CLINIC The Tenth Annual Quality Control Clinic sponsored jointly by this section and the Industrial Management Council of Rochester will be held on Feb. 16, 1954, at the Rochester Chamber of Commerce.

The central theme of this year's clinic is "New Horizons for Quality Control." The 16 technical sessions are divided into two morning and three afternoon series of concurrent talks. The topics to be covered by the five series are: research and engineering, inspection and purchasing, chemical, mechanical and electrical, and general interest.

The luncheon speaker will be Ephraim Freedman, director of Macy's Bureau of Standards; the banquet speaker Arno H. Johnson, vice president and director of research, J. Walter Thompson Co., New York.

General chairman of the Clinic committee this year is John Baker, Eastman Kodak Co., who is determined to make the tenth anniversary program a memorable one.

Complete programs for the Clinic and registration forms can be obtained from: Edward R. Close, Bausch & Lomb Optical Co., 635 St. Paul St., Rochester 2, N. Y.

SAN FRANCISCO BAY AREA This section will be one of several cooperating with the University of California at Berkeley in presenting the Sixth Annual Industrial Engineering Institute on Jan. 29-30, 1954. This institute is sponsored by the University for the purpose of discussing fundamentals and practical applications in the

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field of management and industrial engineering, with special attention devoted to the problems of small business. T. H. Martzloff, McKinsey & Co., and chairman of the section, will present one of the sessions at the institute.

TEXTILE DIVISION The Fifth Annual Textile Quality Control Conference sponsored by the Textile Division of ASQC will be held for three days on Feb. 4-6, 1954 at the North Carolina State College School of Textiles, Raleigh, N. C.

The conference will open on Thursday with a series of plant tours through various local mills. Friday's technical sessions will open with a welcome address by Dean M. E. Campbell of the School of Textiles, and a discussion of ASQC's relationship to textile quality control by A. L. Davis, president of ASQC. A Social hour, banquet and entertainment are planned for Friday evening at the Raleigh Country Club. An elementary training course in quality control will be presented all day Saturday. Concurrently with this course will be further technical sessions in the morning and an advanced educational session on operations research in the afternoon.

VIRGINIA POLYTECHNIC INSTITUTE Beginning in 1954 Virginia Polytechnic Institute, North Carolina State College, University of Florida and the Southern Regional Education Board will jointly sponsor cooperative graduate summer sessions in statistics. The first such session will be conducted by VPI for the six weeks from June 9 through July 17, 1954. Additional summer sessions are tentatively planned for North Carolina State College and the University of Florida in the two following years. Subsequent sessions will be rotated among these or other institutions throughout the south.

During the 1954 session Prof. Maurice Kendall, University of London, will give a course in multi-variate analysis, and Dr. Ralph Comstock, North Carolina State College, will give one in quantitative genetics. Other courses offered during this session will include probability and inference, analysis of variance, statistical methods, engineering statistics, education statistics, rank order statistics and the theory of sequential methods. Each course will carry three semester hours of graduate credit with a maximum of six semester hours permissible. The courses are planned so that they may be taken consecutively in successive summer sessions.

The fee for the VPI session is $30.00. Board, room, P. O. box and laundry for the entire session may be obtained for $76.40. Inquiries should be addressed to Boyd Harshbarger, Head Dept. of Statistics, Virginia Polytechnic Institute, Blacksburg, Va.

WESTERN MASSACHUSETTS A basic course in statistical quality control is to be conducted by this section, starting Feb. 17, 1954 and running for 12 weeks. It will be a one-night-a-weeker under the guidance of Lawrence Mueller and will be held at American International College, Springfield.

American Society News

With a background of over 500 quality control people attending clinics, educational sessions, a banquet and luncheons, and an address by the Governor of Rhode Island, things began to look like a mid-year version of a small national convention. Not only were the Society's Operating and Executive Committees in session at the 7th New England Quality Control Conference, but its Board of Directors also came to Providence from the many corners of the United States.

OPERATING COMMITTEE MEETING

Sheraton-Biltmore Hotel, November 5, 1953: This committee, preparing recommendations to be presented to the Society's Executive Committee, logically was the first of the three national groups to hold sessions. In addition to the usual task of reviewing progress made by the several national committees, and the items reported below, the decisions of particular interest to members were (1) to expedite the completion of the direct mailing of a second set of bills from the National Office to members whose renewals had not yet been received from sections; (2) to transfer the handling of advertising in the May (Convention) Issue of IQC from the General Convention Committee to the Managing Editor; (3) to investigate approaches to making available a current and complete bibliography of quality control literature; (4) to empower the vice president in charge of divisions and technical committees to put into effect the organization of the Staff Operations Committee (resolved by and reported under the September activity of the Executive Committee); and (5) to send a letter to section chairmen announcing the standings of the sections in competition for the Presidential Award for Section Management.

EXECUTIVE COMMITTEE MEETING

Narragansett Hotel (morning), Sheraton-Biltmore Hotel (afternoon), November 6, 1953: The following new section was admitted to the Society:

75 Scranton-Wilkes Barre (Pa.)
Chairman: Carl D. Larson, U. S. Hoffman Mach. Corp., Scranton
Vice Chairman: Alfred S. Wall, Daystrom Instrument Div. of Daystrom, Inc., Archbald
Secretary: John J. Minelli, Eureka Specialty Printing Co., Scranton
Treasurer: Robert A. Zingerman, Daystrom Instrument Div. of Daystrom, Inc., Archbald

After listening to a description of the increasing complexity of the Society's expanding activities, the Committee approved the preparation of a By-Law to provide for a fourth vice president beginning with the 1955-56 fiscal year. Among his duties would be the supervision of the activities of the General Convention Committee and the Regional Conferences Committee.

The Society's Manual on Personnel Policy was approved. Nearing the approval stage is the Examining Committee's proposal to establish, in each section, a local examining committee for formal control of the approval of qualifications of Members and of Senior Members, and to assist in the work of approving transfers to the grade of Fellow.

The national membership figures have continued to improve since the September spurt. The current comparative figures:

Nov. 30, 1952	Nov. 30, 1953
5584	6467

An encouraging aspect of the make-up of these totals is that the number of new members this year is now up to within seven of last year's. The large gain shown above, of course, comes from about 900 more renewals this year.

BOARD OF DIRECTORS MEETING

Narragansett Hotel (morning), Sheraton-Biltmore Hotel (afternoon), November 7, 1953: The third day of the Society meetings was devoted to a meeting, unusual for this time of the Society fiscal year. For the first time the Board of Directors held a "mid-year" meeting. One of the things making the extra assembly practical is the new organizational setup with the much smaller Board.

President Davis opened the meeting with the theme that such meetings would give the Board the opportunity to take a more active part in the management of the Society.

Each officer presented a report that gave a brief summary of the activities in his area of responsibility.

Prior to the meeting, each member of the Board had an opportunity to study the report of the Section Representation Committee concerning redistricting of the Society. Following a thorough discussion, the Board approved with no dissenting

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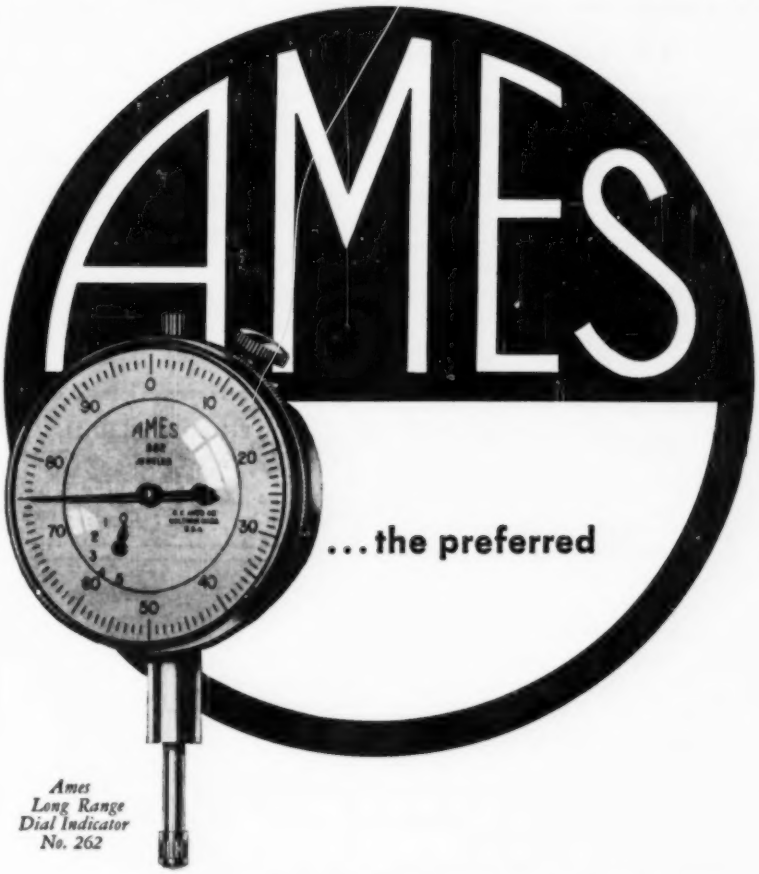

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votes the general guides for redistricting, which were presented. The Executive Committee will now have to work out the actual districts, using the guide as a basis, and present that plan to the Board for approval. The Section Representation Committee was discharged with the thanks of the Board as having completed its assignment.

The second major area of discussion concerned the Society's investment program. This motion passed with a large majority vote (only one vote being recorded against it): That the present program of the Financial Advisory Committee be continued with the proviso that any funds obtained from the sale or calling in of securities, or from dividends or interest paid, cannot be reinvested without prior approval of the Executive Committee.

President Davis recommended that it be the duty of each president early in his administration to raise the question of security investments with the Board.

FELLOWS

On the recommendation of the Examining Committee, the following man has been elected a Fellow of ASQC:

Malcolm W. Blackwood
Baker Perkins, Inc.
Saginaw, Mich.

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NAVAL OFFICER—Graduate management engineer, eight years military experience in acceptance inspection and quality control, five years civilian experience in inspection and quality control of mechanical and electronic equipment. Past section chairman ASQC. To be released from active duty April 4, 1954. Desire position in quality control at management level. Married, will relocate. Please reply to Box 10D2 at the above address.

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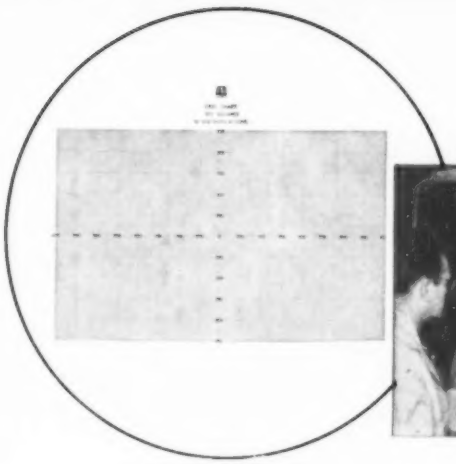

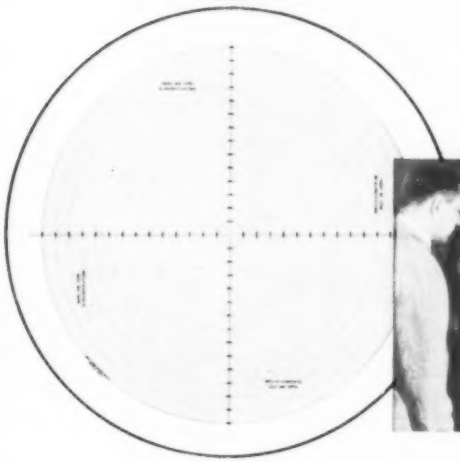

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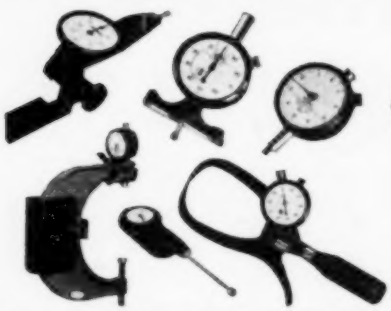

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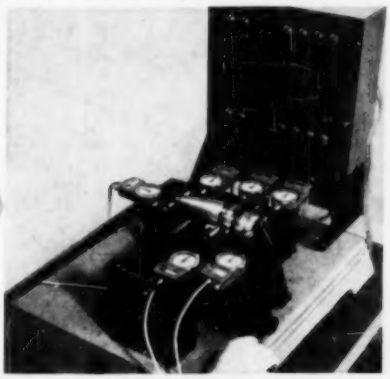

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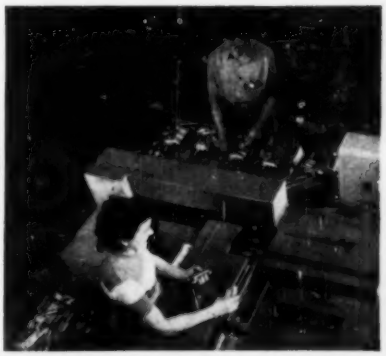

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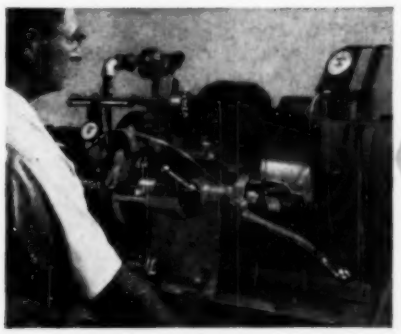

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